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Plasma carotenoid levels as biomarkers of dietary carotenoid consumption: A systematic review of the validation studies

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ABSTRACT

Background: Previous research has demonstrated that plasma carotenoids are a reliable biomarker of usual fruit and vegetable intake. The review aims were to synthesize (i) the mean dietary intake and (ii) plasma concentrations of carotenoids reported from validation studies (iii) compare the strength of the relationship between the two, measured using different dietary assessment methods.
Methods: Six databases were used to locate studies that included: adult populations, assessment of dietary intake, measurement of plasma carotenoids and reported the comparison between the two measures.
Results: One hundred and forty-two studies were included with 95,480 participants, the majority of studies were cross-sectional (n = 86), with randomized controlled trials (RCTs) (n = 18), 14 case–control studies and 13 cohorts. The most common reported dietary carotenoid and plasma carotenoid was lycopene: weighted dietary mean intake (4555.4 ug/day), and plasma concentration 0.62 umol/L (95% CI: 0.61, 0.63, n = 56studies. The strongest weighted correlation between the two measures was found for cryptoxanthin (r = 0.38, 95% CI 0.34, 0.42) followed by a-carotene (r = 0.34, 95% CI 0.31, 0.37).
Conclusion: This review summarizes typical dietary intakes and plasma concentrations and their expected associations based on validation studies conducted to date which provides a benchmark for future validation studies.

1. Introduction

Epidemiological studies have reported that regular consumption of fruits and vegetables, in accordance with World Cancer Research Fund guidelines [1], is associated with reduced risk of some cancers including breast, oesophageal and lung [2–6]. In addition having an adequate fruit and vegetable intake substantially lowers risks of coronary heart disease [7,8], stroke [9,10] and type 2 diabetes mellitus [11,12] specifically showing decreased risk with higher consumption of green leafy vegetables [13,14]. In addition fruit and vegetable intake has been associated with decreased risk of asthma in adults and children [15].

A variety of plant components such as fiber, carotenoids and other phytochemicals are thought to contribute to these protective effects [16]. Carotenoids are obtained from the diet as brightly coloured pigments which originate in plant foods. Variations in digestion and absorption exist between individuals, with plasma concentrations of carotenoids having a half-life between 26 and 76 days [17]. However some carotenoid supplement studies report peak concentrations in plasma up to two weeks following consumption [18].

The main carotenoids of interest are lycopene and β-carotene and this is because of the documented associations with decreased risk of disease. These carotenoids are highly prevalent in fruits and vegetables. Specifically lycopene is found in tomatoes and tomato based products while β-carotene is found in high concentrations in carrots and cantaloupe. Other carotenoids including cryptoxanthin are found in fruits such as oranges, while lutein is found in lettuce, kale and spinach [19]. Lutein is often combined with zeaxanthtin in reports due to chromatographic overlap.

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Accurate assessment of fruit and vegetable intakes is fundamental to a range of research domains, including epidemiological studies examining the relationship between dietary intake and disease outcomes, evaluating whether populations are consuming adequate intakes of fruit and vegetables and hence obtaining the protective advantage from disease and monitoring of changes in population intakes over time. Measuring the dietary intake of carotenoids and examining the relationship with plasma carotenoid concentrations is one way in which intake can be scrutinized using an independent biomarker and the validity of intake assessment method evaluated.

Validity is defined as the accuracy of a measure, assessed by comparing results from an assumed "gold standard" measure of known validity such as doubly labelled water, to values obtained by another instrument. In free living individuals, there is no gold standard measure of total or individual nutrient intakes when comparing actual intake with that measured using a dietary assessment method or tool [20]. However, comparison of one dietary intake assessment method to another method is a common approach, but does carry the risk of correlated errors [21,22]. Plasma biomarkers offer an objective and independent variable that can act as a proxy for intake of specific foods and therefore is suitable for use when validating dietary assessment tools [23]. Regardless of individual variability in absorption, availability, and metabolism [24,25], plasma concentrations of carotenoids reflect intake of fruits and vegetables due to their abundance in these foods [24]. Due to the diverse phytochemical composition across a range of vegetables and fruits, selecting a single carotenoid as sole biomarker is not likely to be meaningful [26]. Instead, a range of carotenoids is recommended when using them as biomarkers of fruit and vegetable intake. Previous research has shown a dose–response relationship between intake and appearance of carotenoids in plasma [27], making carotenoids a fairly reliable biomarker of total carotenoid intake However, the strength of the relationship between intake of individual dietary carotenoids and plasma concentrations across a range of studies has not been ascertained. Establishing reference ranges for diet and plasma carotenoids, could allow comparison of specific dietary tools in terms of validity statistics in measuring dietary intakes of carotenoids and/or fruits and vegetables.

Therefore the aims of this review were to synthesize from the best available dietary validation studies to date (i) the mean dietary intake of carotenoids in adults; (ii) the mean plasma carotenoid concentrations reported in dietary validation studies (iii) the strength of the relationship between dietary intakes of carotenoids, measured using different dietary intake assessment methods, and plasma carotenoid concentrations.

2. Methods

A three-step strategy was undertaken to identify studies published in the English language up to May 2014. The review methodology was registered with PROSPERO (ID number CRD42013004777).

In stage one, six online databases were searched, CINAHL, Cochrane, MEDLINE, ProQuest, PubMed and Excerpta Medica. Key words used individually and in combination were: dietary assessment OR food frequency questionnaire OR diet/dietary recall, diet record, weighed food record, validity/validation AND carotene OR carotenoids OR fruit OR vegetable. Electronic searches were supplemented by manual cross checking of the reference lists of relevant publications. All study designs were included.

After the removal of duplicates, stage 2 involved the assessment of titles and abstracts of identified studies by two independent reviewers with discrepancies decided by consensus using a third reviewer. *A'priori* inclusion/exclusion criteria were applied to determine the eligibility of each publication for inclusion in the review, as per the following inclusion criteria: adult populations ($\geq$18 or 19 $\geq$ yrs or 'adults' depending on the database searched), a measure of dietary intake, a measure of plasma carotenoids as a biomarker of intake, reported the comparison/correlation/agreement between diet and biomarker assessments. Carotenoids, individually or in combination, included α- and β-carotene, cryptoxanthin, lycopene, zeaxanthin, and lutein. Papers that met the inclusion criteria, or where eligibility was unclear, were retrieved. These were then evaluated for inclusion by two independent reviewers with discrepancies discussed with a third person.

Risk of bias was assessed using a standardized tool from the American Academy of Nutrition and Dietetics [28]. Ten quality criteria were rated as being absent, present or unclear in each study. This included the assessment of population bias, study blinding, a description of the intervention and assessment tool, statistical methods, and study funding. An overall quality rating was assigned to each study as being plus/positive, neutral or minus/negative.

Data were extracted using standardized tables developed for this review. In cases of uncertainty regarding quality assessment, or data extraction, a third independent reviewer was consulted until consensus was reached.

The dietary intakes of carotenoids and plasma carotenoid concentrations, and the relationship between them, were grouped by dietary assessment method where possible. These dietary intake assessment methods were 24 h recall, food frequency questionnaire (FFQ), diet history, food records, and other non-standard dietary questionnaires which included dietary methods not covered by the other categories.

2.1. Data synthesis

Results were pooled using meta-analysis if the following data were available in addition to the reported number of participants: correlation coefficients (or equivalent) between dietary carotenoid intake and plasma carotenoid concentrations (α carotene, β carotene, cryptoxanthin, lutein/zeaxanthin and lycopene); dietary intakes (reported as μg/day) and plasma concentrations. For plasma concentrations the data were entered as μmol/L and if reported in other units they were converted to μmol/L using the relevant conversion factors. If there was significant heterogeneity, the random effects model was used for statistical analysis. If studies reported more than one correlation statistic between diet and plasma due to use of multiple dietary assessment methods, the strongest correlation was used (n = 3 studies).

Analysis were undertaken by each individual carotenoid and also separately for each diet assessment method (24 h recall, FFQ, diet history, food record and questionnaire) and where possible, overall regardless of diet assessment method. Sub-analysis by sex was also undertaken if there were enough studies to conduct separate meta-analyses. The reporting of the associations between diet and plasma carotenoid concentrations was rarely separated out by supplement use versus no use, supplements were most often added into dietary intake estimates thus the impact of supplements could not be compared in this review.

There were not enough studies for comparison by ethnicity. Meta-analyses were conducted using Comprehensive Meta-Analysis Professional version 2 (Englewood, New Jersey, USA).

3. Results

The search strategy identified 4176 articles, as outlined in Fig. 1. For the full search strategy see Supp Table 1. Following elimination of duplicates, initial assessment of titles and abstracts, and

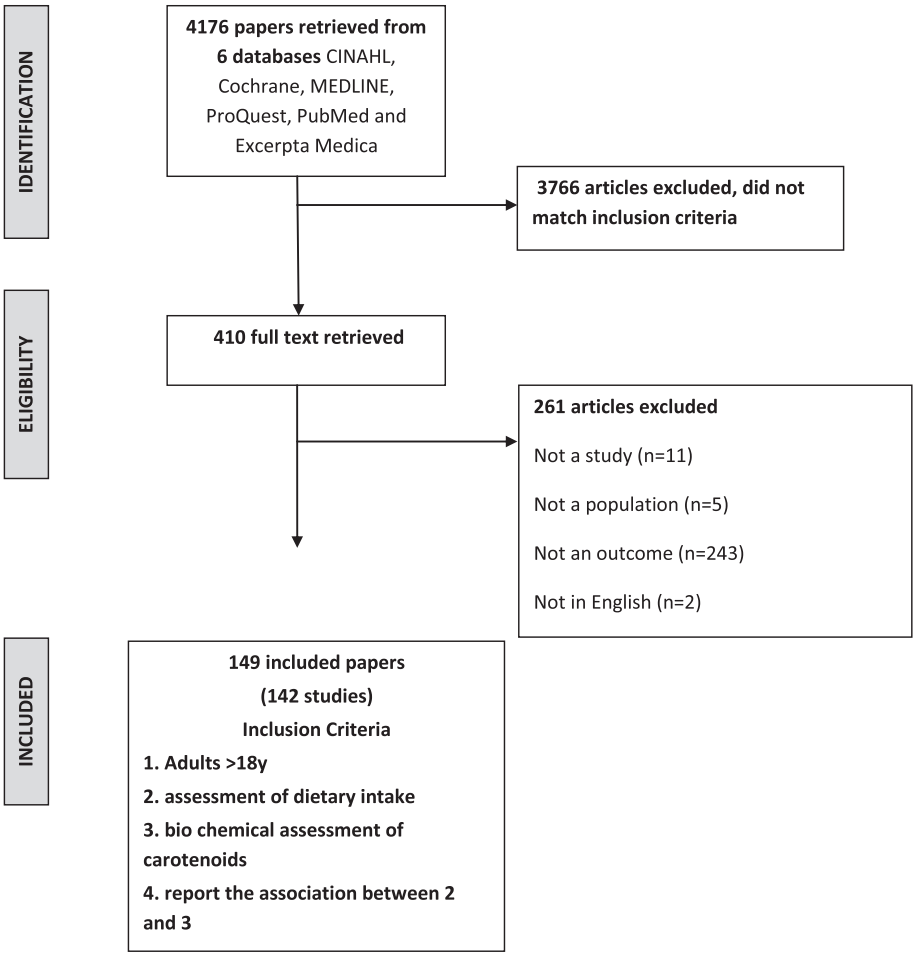

Fig. 1. Flow diagram of article identification retrieval and inclusion for the systematic review.

evaluation of retrieved studies against the inclusion criteria, 149 articles from 142 studies were identified for critical appraisal and included in the review.

The results of the quality assessment appraisal are summarized in Supplementary Table 2. The majority of included studies were classified as being of positive quality (n = 111, 77%), with ten (7%) classified as being of negative quality and 23 (16%) of neutral quality. Ten percent of studies (n = 13) did not describe the handling of withdrawals or non-completers and the majority of studies only conducted correlation analysis and not other validation statistics such as Bland Altman and Kappa statistics. As the inclusion criteria for the current review included all study types, a large proportion of the studies were cross-sectional and appropriately deemed as "not applicable" against the criteria of "assessing the comparability of study groups" (n = 92, 65%) and "description of intervention" (46%).

As shown in Table 1, over half of the studies (n = 69) were conducted in the USA with the next most common regions being the UK (n = 9), France (n = 7), Italy (n = 6) and the Netherlands (n = 5). The majority of included studies were cross-sectional (n = 86), followed by randomized controlled trials (RCTs) (n = 18) with 14 studies for case–control and 13 for cohort. The total number of participants was 95 480 across the included studies. The majority of studies included healthy individuals free of disease and not taking medications and assessed both sexes with 31 assessing females only and six studies conducted in males only [19,24,29–37].

3.1. Diet

In descending order the most common dietary assessment methods used were: food frequency questionnaires (n = 103 studies), 24 h recalls (n = 35), food diary/estimated food records (n = 30) with reporting period between one and seven days, generic food questionnaire or fruit and vegetable screeners (n = 11), weighed food records (n = 10) with reporting periods varying between two and seven days, diet history method (n = 6) and diet quality score (n = 2). Of those studies which utilised an FFQ, a total of 36 studies provided extra details regarding the reporting period. The most common reporting periods were the: previous 12 months (n = 23), previous three months (n = 7) and previous month (n = 7). A total of 58 studies reported details on the number of items within an FFQ, with a mean number of 128 food items (range 27–255). There were 43 studies which assessed dietary intake using two of the above methods simultaneously, while five studies [20,38–41] used three or more methods within the same study. As shown in Table 2, the most common dietary carotenoids assessed were: β-carotene (n = 88 studies), followed by lycopene (n = 47) and α-carotene (n = 46). Thirty eight studies assessed lutein and zeaxanthin as a combined variable, while only 18 assessed lutein and seven zeaxanthin individually. Sixteen studies assessed dietary intake as intake of fruits and vegetables only, rather than individual carotenoid intakes. The nutrient databases used to evaluate dietary carotenoids varied with over 21 different databases used. The most common however was the

Table 1
Description of included studies.

Source	Country	Study design	n	Gender	Age	Dietary method + reporting period	Dietary carotenoids assessed	Nutritional database used	Biochemical carotenoids assessed	Biochemical method	Fasting time length
AAA Epic group, (1997) [61]	Spain	Cohort	64	47% M	35–60 yrs	Diet history (baseline & 12 months) 12 × 24-hr recalls during the 12 months	β-carotene	EPIC nutrient database for nutritional epidemiology	b-carotene, a-carotene, cryptoxanthin, lycopene, luteinzeoxanthin,	HPLC	12 h fast
Alberti-Fidanza et al. (1998) [62]	Italy	Cross sectional	79	44% M	>30 yrs	Diet history + 2-day WFR, 2-day duplicate portion chemical analysis	β-carotene, retinol	European food composition tables	β-carotene, a-	HPLC	12 h fast
Al-Delaimy et al. (2005) [44]	France, Italy, Sweden, Netherlands, Denmark, Spain, Germany, UK, Greece	Prospective cohort	2969	NR	≥45 yrs	Food questionnaires (FQ) Dietary method differed for each country. FQ were either extensive, semi-quantitative, diet history, food record or 24hr recall.	Fruits and vegetables	EPIC nutrient database for nutritional epidemiology	Lutein, zeaxanthin, b-cryptoxanthin, lycopene, a-carotene, β-carotene	HPLC	NR
Allen et al. (2003) [63]	USA	RCT	40 (36 completed)	50% M	18–65 yrs	Daily checklist of lycopene containing foods to assess compliance with allocated diets. 3-day FR (3 time points over 6 weeks)	Lycopene (3 groups -tomato sauce, tomato soup and tomato juice)	USDA food composition database	Lycopene, a-carotene, b-carotene, lutein, b-cryptoxanthin, zeaxanthin,	HPLC	Fasting
Anderson et al. (2005) [64]	Norway	Cross sectional	100 with 3 measures; 86 with 4 measures.	100% M	20–55 yrs	14 day 3 d WFR (5 periods/1 week apart 180-item FFQ (8 veg questions, 8 fruit questions, dietary supplements), 27-item FFQ.	Fruits and vegetables.	Database developed by Department of Nutrition, University of Oslo.	Lutein, zeaxantin, lycopene, a-carotene, b-carotene	HPLC	12hr fast
Arab et al. (2011) [65]	USA	Prospective cohort	262	33% M	21–69 yrs	24 h recalls using web-based *DietDay* - 9349 foods, >7000 food images + 124 item diet history FFQ.	a-carotene, b-carotene, b-cryptoxanthin, lycopene, and the combined intakes of lutein and zeaxanthin.	USDA food composition database and National Cancer Institute database.	Lycopene, a-carotene, b-carotene, b-cryptoxanthin and combined lutein + zeaxanthin	HPLC	10hr fast
Arnaud et al. (2001) [31]	Cuba	Prospective cohort	106	100% M	27–59 yrs	Semi-quantitative FFQ (7 consecutive days at 4 time points over a 1yr period)	Total carotenoids	Cuban NUTRISIS food composition database	Lycopene, a-carotene, b-carotene, b-cryptoxanthin, lutein-zeaxanthin,	HPLC	12hr fast
Bermudez et al. (2005) [66]	USA	Cross sectional	584	41% M	≥60 yrs	118-item semi-quantitative FFQ. 13 fruit, 23 vegetable items plus dietary supplement use.	a-carotene, b-carotene, b-cryptoxanthin, lutein, zeaxanthin, and lycopene + b-carotene from supplements.	MN (Minnesota?) Food and Nutrient Database	a-carotene, b-carotene, lycopene lutein, zeaxanthin, b-cryptoxanthin,	HPLC	12hr fast
Bernstien et al. (2002) [67]	USA	RCT	70	20% M	≥70 yrs	Modification of Gladys Block FFQ. Food list collapsed into 32 food groups.	a-carotene, b-carotene, cryptoxanthin, lutein, lycopene,	NR	a-carotene, b-carotene, cryptoxanthin, lutein, lycopene,	NR	12hr fast
Bingham et al. (1995; 1997) [68–71]	UK	Prospective cohort	160	160	50–65 yrs	4-day weighed food records at 4 timepoints over 12 months - 2 FFQs (each with 130 food items) were completed - 27% of question related to vegetables in Cambridge FFQ and 18% in Oxford., 2 variants of the 24hr recall (structured/ unstructured) and 3 types of food diary (7-day record + 2 checklists).	b-carotene equivalents	Food tables	a-carotene, b-carotene, cis-carotnen, b-cryptoxanthin, lutein, lycopene,	Absorptiometric detection	Overnight fast
Block et al. (2001) [24]	USA	Cross sectional	116	100% M	35–72 yrs (Mean 52 yrs)	60-item FFQ (National Cancer Institute)	Fruits and vegetables	National Cancer Institute software.	b-carotene, cryptoxanthin,	HPLC	NR

						including 10 vegetable and 6 fruit items.					
Bodner et al. (1998, 1999) [72,73]	UK	Cross sectional	273	NR	39–45 yrs	Self-administered FFQ	b-carotene	UK National Nutrient Databank	b-carotene	HPLC	Avoid fruit and fruit juice 6 h prior
Boeing at al (1997) [74]	Germany	Longitudinal Cross sectional	92	47% M	35–64 yrs	Self-administered 158-item FFQ (baseline and 12-months) + 24hr recalls monthly/12 months	a-carotene + b-carotene (combined)	Federal Coding System (V 2.1)	a-carotene + b-carotene (combined)	Unclear	NR
Bogers et al. (2003; 2004) [45,75]	Netherlands	RCT (2003 only reports Cross sectional data; 2004 report additional follow-up data)	161	100% F	41 ± 4 yrs	106-item semi-quantitative FFQ assessing food intake over the previous month. −17 fruit items, 21 cooked vegetable items, 14 raw vegetable items and 5 fruit juice items. Completed at baseline, 1 + 12 months.	total vegetables, cooked vegetables, raw vegetables, fruit, fruit juice	Unclear	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein,	HPLC	Overnight fast
Bolton-Smith et al. (1991) [76]	UK	Cross sectional	196	100% M	45.8 ± 2.9 yrs	FFQ	b-carotene	McCance and Widdowson's The Composition of Foods	Carotenes	Unclear	NR
Bone et al. (2000) [77]	USA	Cross sectional	19	16% M	18–59 yrs	Health Habits and History questionnaire frequency of consumption weekly, monthly, yearly.	Lutein + zeaxanthin	Nutritionist V (First Data Bank, CA, USA).	Lutein + zeaxanthin	HPLC	Not fasting
Bowman et al. (2011) [78]	USA	Case control	38	50% M	Mean: 74 yrs	124-item FFQ (National Cancer Institute) assessing intake over the previous 12 months. Completed at baseline and 1 month.	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	National Cancer Institute Diet*Calc version 1.4.3	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	HPLC	Overnight fasting
Brantsaeter et al. (2007) [79]	Norway	Cross sectional	119	100% F	Range 23–44 yrs, Mean 31 yrs	Semi-quantitative 255-item FFQ with additional items on dietary supplements. + 4-day weighed food record	b-carotene, total carotenoids	FoodCalc and Norwegian food composition table.	b-carotene	HPLC	Non-fasting
Brunner et al. (2001) [80]	UK	Cross sectional	860	53% M	39–61 yrs	127-item FFQ including questions of supplement intake. + 7-day diet diary including photos of portion sizes.	Carotenes (b-carotene activity)	4th and 5th versions of McCance and Widdowson's The Composition of Foods	b-carotene	HPLC	4–8 h
Burri et al. (2010) [81]	USA	Cross sectional	49	51% M	Mean ± SD 39.7 ± 12.3 yrs	FFQ developed from US national dietary intake + 3-day diet record was completed with photos provided to estimate portion size.	lycopene	Block dietary data systems to analyse FFQ and USDA for 3-day diet record.	Lycopene	HPLC	Overnight fast
Campbell et al. (1994) [82]	USA	Cross sectional	99	51% M	18–37 yrs	FFQ	Foods high or low in carotenoids	Food carotenoid composition data	Lutein; cryptoxanthin; Lycopene; a-carotene; b-carotene	HPLC	Fasted overnight
Canfiled et al. (1997) [83]	USA	RCT	12	100% F	23–36 yrs	3 × 24-h dietary-intake records completed incl. weekdays and I weekend day.	α-carotene, β-carotene, lutein, lycopene	US Department of Agriculture (USDA) Continuing Survey of Food Intake II-86 database.	α -carotene, β -carotene, lutein plus zeaxanthin, β -cryptoxanthin, lycopene	HPLC	Fasted
Canfield et al.,)2001) [84]	Honduras	RCT	97	100% F	15–43 yrs	24-h dietary recall	Not determined	UC	α -carotene, β -carotene, lutein plus zeaxanthin, β -cryptoxanthin, lycopene	HPLC	Non-fasted

(*continued on next page*)

Table 1 (*continued*)

Source	Country	Study design	n	Gender	Age	Dietary method + reporting period	Dietary carotenoids assessed	Nutritional database used	Biochemical carotenoids assessed	Biochemical method	Fasting time length
Cappuccio et al. (2003) [85]	UK	Cross sectional	271	39% M	18–70 yrs	24-h dietary recall	Not determined	NR	b-carotene only	HPLC	Non-fasted
Carlsen et al. (2011) [86]	Norway	Cross sectional	147	UC	18–80 yrs	7-d weighed food records	Not determined	Food database AE-07 and KBS software system (KBS, version 4.9, 2008)	α-carotene, β-carotene, lutein, zeaxanthin, β-cryptoxanthin, lycopene	HPLC	Fasted
Carroll et al. (1999) [87]	Ireland	Cross sectional	118	50% M for 24 −45yrs 46% M > 64 yrs group	n = 64 for 24–45 y and n = 54 for >65 y groups	7-d estimated food records and FFQ	α -carotene, β -carotene, lutein plus zeaxanthin, β -cryptoxanthin, lycopene	Reference to dietary analysis programme, Comp-Eat (Nutrition Systems, London, UK).	α -carotene, β -carotene, lutein plus zeaxanthin, β -cryptoxanthin, lycopene	HPLC	NR
Cartmel et al. (2005) [88]	USA	RCT	57	72% M 28% F	>21 yrs	FFQ to determine F & V intakes	Not determined	serves of F & V	α -carotene, β -carotene, lutein, zeaxanthin, β -cryptoxanthin, lycopene	HPLC	NR
Cena et al. (2008) [89]	Italy	Cross sectional	87	100% F	20.25 yrs	FFQ validation by 7-d food records	lutein and zeaxantin	USDA-NCI carotenoid database	lutein and zeaxanthin	HPLC	fasted
Cena et al. (2009) [90]	Italy	Cross sectional	21	100% F	24–42 yrs	FFQ	lutein	USDA-NCI carotenoid database	lutein	HPLC	fasted
Chung et al. (2009) [91]	USA	Cross sectional	25	52% M	31.9 ± 2.0 yrs	FFQ	α -carotene, β -carotene, lutein plus zeaxanthin, β -cryptoxanthin, lycopene	DietSys (version 3.7) nutrient analysis software	α -carotene, β -carotene, lutein plus zeaxanthin, β -cryptoxanthin, lycopene	HPLC	fasted
Ciulla et al. (2001) [92]	USA	Cross sectional	280	49% M	18–50 yrs	FFQ	Dietary β - carotene and lutein plus zeaxanthin	University of Minnesota Nutrition Coding Centre Database	β - carotene and lutein plus zeaxanthin	HPLC	NR
Coates et al. (1991) [93]	USA	Cross sectional	91	100% F	30–69 yrs	FFQ	α-carotene, β-carotene, lutein, β-cryptoxanthin, lycopene	USDA	α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	HPLC	Non-fasting
Cooney et al. (1995) [94]	USA	Cross sectional	21	48% M	31–63 yrs	FFQ	NR	USDA	α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	HPLC	Fasted
Curran-Celentano et al. (2001) [95]	USA	Cross sectional	280	NR	36 ± 7.9 yrs (Mean ± SD)	FFQ	β-carotene; lutein + zeaxanthin; lycopene	USDA	β-carotene; lutein; zeaxanthin; lycopene	HPLC	NR
Dauchet et al. (2008) [96]	France	Randomised, double-blind, placebo-controlled, primary-prevention trial	3521	42% M	35–60 yrs	6 × 24 h dietary records	F & V	UC	β-carotene	HPLC	Fasted
Daures et al. (2000) [97]	France	Cross sectional	87	29% M	41.9 ± 11.8 yrs	FFQ	β-carotene	UNIDAP	Plasma β-carotene	HPLC	Fasted
Dixon et al. (1996) [98]	USA	Cross sectional	10	70% M	24–65 yrs	4 × FFQ and 10 × 3-d food records	Dietary total carotenoids	ESHA nutrient database, version 3.0	Serum α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	HPLC	Fasted
Dixon et al. (2006) [99]	USA	Cross sectional	130	34% M	>20 yrs	1 × FFQ and 4 × 24hr food recalls	α carotene, β carotene, lutein + zeaxanthin, cryptoxanthin	University of Minnesota Nutrition Data System for Research (NDSR)	Serum α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	HPLC	Fasted
Eliassen et al. (2006) [100]	USA	Cross sectional	214	51% M 49% F	Mean − 47.7 yrs	FFQ	F & V and supplements	NCI	Serum α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	HPLC	NR

El-Sohemy et al., 2002 [101]	Costa Rica	Case control study	459	75% M	Men 56 ± 11 Women 59 ± 10 yrs	FFQ and 7 d food record	α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	USDA	Serum α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	HPLC	Fasted
Enger et al. (1995) [102]	USA	Case control study	215	63% M	50–74 yrs	FFQ	α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	Nutrient data base Mangels et al. (1993).	Serum α-carotene, β-carotene, lutein plus zeaxanthin, β-cryptoxanthin, lycopene	HPLC	Fasted
Faure et al. (2006) [103]	France	Cross sectional	12,741	39% M	35–60 yrs	6 d food records	β-carotene	SU.VI.MAX computer	β-carotene	HPLC	Fasted
Fawzi et al. (2004) [104]	USA	Cross sectional	204	100% F	AA 30.0 (6.1) Caucasian 32.5 (4.0)	FFQ	α-carotene, lutein plus zeaxanthin, lycopene	USDA	Serum α-carotene, lutein plus zeaxanthin, lycopene	HPLC	NR
Ferrari et al. (2005) [105]	9 European countries	Cross sectional	2910	48% M	NR	FFQ & 24 h food record	a-carotene, b-cryptoxanthin, and lycopene	EPIC	a-carotene, b-cryptoxanthin, and lycopene	NR	NR
Floreani et al. (2000) [106]	Italy	Case control study	210	16% M	51.5 ± 10 yrs	FFQ	F&V	UC	lutein, zeaxanthin, lycopene, b-carotene, a-carotene, b-cryptoxanthin	HPLC	NR
Forman et al. (1993) [46]	USA	Cross sectional	57	100% M	20–40 yrs	Health Habits and History Questionnaire (FFQ)100 items with 16 items fruit, 19 vegetables + 7 d food diary checked by dietitian at end of study for completeness	α -carotene, β -carotene, lutein plus zeaxanthin, β -cryptoxanthin, lycopene	USDA carotenoids	α -carotene, β -carotene, lutein plus zeaxanthin, β -cryptoxanthin, lycopene	HPLC	Fasted
Freedman et al. (2010) [107]	USA	cohort	1811	100% F	50–79 yrs	FFQ	lutein plus zeaxanthin	Nutrient and food group estimates were computed at the Fred Hutchinson Cancer Research Center, Seattle, Washington	Lutein and zeaxanthin	NR	Fasted
Freisling et al. (2009) [108]	Austria	Cross sectional	226	27% M	55–98 yrs	FFQ & 1-day estimated food record	lutein, zeaxanthin, b-carotene, a-carotene, b-cryptoxanthin	Department of Nutritional Sciences of the University of Vienna	Lutein, zeaxanthin, b-carotene, a-carotene, b-cryptoxanthin	HPLC	Fasted
Galan et al. (2005) [109]	France	RCT	3128	42% M	F = 35–60; M = 45-60	6 × 24-hr recalls over 18 months (4 week days and 2 weekend days	β - carotene	French CIQUAL table + Mc Cance and Widdowson's	β-carotene	HPLC	12 h
George et al. (2012) [38]	USA	Cross sectional	470	54% M	F = 53 ± 8 yrs; M = 54 ± 8 yrs	1 × diet history questionnaire -FFQ (prev 12 m) + 2(min) × 24R (103–105 days apart) +F&V screener(past 1 m)	a-carotene, cis- and trans-b-carotene,cis- and trans-b-cryptoxanthin, lutein, zeaxanthin, and cis- and trans-lycopene	FFQ -1994–96 (CSFII) Nutrition Data Systems for Research (NDS-R) from the University of Minnesota +24R (Food intake Analysis System	a-carotene, cis- and trans-b-carotene,cis- and trans-b-cryptoxanthin, lutein, zeaxanthin, and cis- and trans-lycopene	HPLC	Fasted
Gerber et al. (2000) [110]	France	Cross sectional	146	47% M	49 ± 14	1X FFQ (PAST 12M)	Total carotenoids	UNIDAP	a-carotene, b-carotene,b-cryptoxanthin, lutein, lycopene	HPLC	NR
Gomez-Aracena et al. (2003) [111]	Spain	Cross sectional	51	100% F	62 ± 5	48 h recall (2 successive days) + FFQ	a-carotene, b-carotene, lycopene	Spanish Food Comp Tables	a-carotene, b-carotene, lycopene	HPLC	NR
Goodman et al. (1996) [112]	USA	Cross sectional	1182	M & F	Median (IQR): A-EM = 56(51–63); H-SM = 58(53–62); H-SF = 58(53–62)	FFQ + data on vitamin supp use	b-carotene	USDA	b-carotene	HPLC	Not fasted
Greene et al. (2008) [113]	USA		295 (3 sites: URI = 176, IIT/ Rush = 57, Emory = 276)	M&F	Adults with 40% > 60 yrs	Multiple pass 24R + FV screener	NR specifically	NR	a-carotene, b-carotene,b-cryptoxanthin, lutein/ zeaxanthin, lycopene	HPLC	Fasted
Grievink et al. (1999) [114]	Netherlands	Cross sectional	227	49% M	59.8 ± 6.3 yrs	FFQ (past 12m)	b-carotene	NR	b-carotene	HPLC	NR

(*continued on next page*)

Table 1 (*continued*)

Source	Country	Study design	n	Gender	Age	Dietary method + reporting period	Dietary carotenoids assessed	Nutritional database used	Biochemical carotenoids assessed	Biochemical method	Fasting time length
Hallfrisch et al. (1994) [115]	USA	Cross sectional -	431	54% M	20–95 yr	7-day diet record + vit supp	Carotenes	USDA, McCance & Widdowson, Pennington & Church, Dicks,Physician's Desk Reference fir Non-prescription Drugs	b-carotene	HPLC	Fasted
Hammond et al., 1995 [116]	Finland	Cross sectional	20 (ten pairs)	F = 6 pairs; M = 4 pairs	19–22 yrs	FFQ (100 items; time frame not specified)	b-carotene, lutein/ zeaxanthin, lycopene, cryptoxanthin	Health Habits & History Questionnaire Diet System Analysis Software (v3)	Lutein, zeaxanthin, b-carotene	HPLC	NR
Hann et al., 2001 [117]	USA	Cross sectional case control	340	100% F	All = 21–80 yr; mean ± SEM = 49.9 ± 0.6 yr	3-day food record, Healthy Eating Index score calculated	b-carotene	USDA + food manufacturers (in program NUTRITIONIST IV)	a-carotene, b-carotene,b-cryptoxanthin, lutein, lycopene (n = 333)	HPLC	Fasted
Hebert et al., 1994 [118]	USA	Cross sectional	167	56%M	mean ± SD: 39.0 ± 11.6	FFQ (timeframe NR)	b-carotene	University of Minnesota's Nutrition Data System	b-carotene	NR	Fasted
Hercberg et al., 1994 [119]	France	Cross sectional	834	M&F	18–97 yr;	Dietary survey interview by dietitian (101 food/ beverage items collected) + previous 6 m	b-carotene	French self database	b-carotene	HPLC	Fasted
Hendrickson et al. (2013) [19]	USA	Case control?	2787	100% F	30–35 yrs	FFQ with supplements assessed also (supplement users later excluded from analysis)	a-carotene b-carotene, b- cryptoxanthin lycopene, lutein/ zeaxanthin	USDA	a-carotene b-carotene, b- cryptoxanthin lycopene, lutein/ zeaxanthin	HPLC	Fasted (approx. 7 h)
Hiraoka et al. (2001) [120]	Japan	Cross sectional	150	100% F	21–22 yr	3-day WFR	b-carotene	Standard Tables of Food Composition in Japan	b-carotene	HPLC	Fasted
Hodge et al. (2009) [121]	Australia	Cohort	3100	35% M	Mean ± SD: M = 55.3 ± 8.5; F = 54.5 ± 8.5	FFQ (including supps) - prev 12 months	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein/ zeaxanthin	USDA	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein/ zeaxanthin	HPLC	NR
Holmes et al. (2007) [32]	USA	Cross sectional	104	100% M	Mean ± SD = 63.3 ± 7.5	FFQ	lycopene, b-carotene	USDA (+McCance & Widdowson's, journals and manufactures	Lycopene, a-carotene, b-carotene	HPLC	Not fasted
Iribarren et al. (1997) [122]	USA	Case Control	323	60%M	Mean ± SD = 59 ± 5	FFQ (66 item), past 12 m	pro-vitamin A carotenoids	NR	b-carotene	HPLC	Fasted
Jacques et al. (1995) [123]	USA	Cross sectional	471	31% M	≥65 yrs	3-d food record	total carotenoids	GRAND + USDA for carotenoids	Total carotenoids	HPLC	NR
Jansen et al. (2004) [124]	Netherlands	Cross sectional	591	48% M	20–59 yrs; mean ± SD: M = 39.5 ± 11.5; F = 39.6 ± 11.6	FFQ (178 item); past 12 months	Fruit and veg only reported	n/a	a-carotene; b-carotene, b-cryptoxanthin, luetin, lycopene, zeaxanthin, canthaxanthin	HPLC	Not fasted
Jarvinen et al. (1993) [125]	Sweden	Cross sectional	341	male and female	Mean 56.8 ± 12.1	Diet history interviews for previous 1 yr period	α -carotene, β - carotene, gamma carotene, lutein, lycopene	Finnish foods database	β - carotene	HPLC	Yes 8 h
Jilcott et al. (2007) [33]	USA	RCT	236	1005 M	40–64 yrs; ave 53 yrs	Dietary Risk Assessment (54Q) + FFQ (136 item) (n = 104 completed)	Fruit and veg only reported	NR	a-carotene; b-carotene, b-cryptoxanthin, luetin, lycopene, zeaxanthin	HPLC	Fasted
Kabagambe et al. (2001) [126]	Costa Rica	case–control study	120	65% M	Mean ± SD = 59 ± 10	FFQ (past 12 m) + 7 × 24R (7/12m) (ref) + FFQ (1 yr later)	a-carotene, b-caroten, b-cyrptoxanthin, lycopene, and zeaxanthin + lutein	USDA	a-carotene, b-caroten, b-cyrptoxanthin, lycopene, and zeaxanthin + lutein	HPLC	Fasted
Kanetsky et al. (1998) [127]	USA	case–control	145 (total): 32 with cervial dysplasia, 113 controls	100% F	≥18 yrs	FFQ (60 items, past 12m)	a-carotene, b-carotene, lycopene, cryptoxanthin, luetin	HHHQ-DIETSYS V 3.0	a-carotene, b-carotene, lycopene, cryptoxanthin, luetin	Radioimmunoassay techniques	Yes
Kant et al. (2002) [128]	USA	Cross sectional	13,400	F = 6948; M = 6452	≥20 yrs	24hr recall	NR specifically; F&V intake (in addition to various quantitative ax)	USDA	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein/ zeaxanthin	See ref paper#29 & 30	

Kant et al. (2005) [129]	USA	Cross sectional	8719	49% M	≥20 yrs < 50 yr = 5896; ≥50 yrs = 2764	24hr recall +3 diet quality scores: Healthy Eating Index (HEI); Recommended Food Score (RFS); Dietary Diversity Score (DDS-R)	NR	NR	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein/ zeaxanthin	NR	Fasted
Kardinaal et al. (1995) [130]	Netherlands	Cross sectional	85	45% M	50–70 yrs; mean ± SD, M = 59.5 ± 6.3, F = 58.3 ± 5.9	FFQ (95 item; prev 12 mths)	b-carotene	Dutch Food Composition Table	b-carotene	HPLC	Not fasted
Katsouyanni et al. (1997) [131]	Greece	longitudinal	80	53% M	25–67 yrs	2× FFQ (190-items, previous 12 mths) + 12 × 24hr recalls 1 per mth in between FFQs	b-carotene	Composition of Greek Foods and Dishes	a-carotene b-carotene	HPLC	Fasted
Kiely et al. (1999) [132]	Ireland	Case control	66	100% F	16–40 yrs	FFQ	b-carotene	Compeat 4 + EU AAIR for carotene	b-carotene	HPLC	Not fasted
Knutsen et al. (2001) [133]	USA	longitudinal	193	M&F	Mean ± SD B: total = 47.2 ± 14.8; F = 46.0 ± 13.7; M = 49.3 ± 16.5.	4 × 24hr recall + FFQ (200 item, time not specified) + 4x 24hr recall − 8 24 h recall collected over ~6mths	Carotene	Nutritional Data Systems	Carotene	spectrophotometry method (Deluca - ref#26)	Fasted
Kobayashi et al. (2011) [134]	Japan	Cross sectional	215	47% M	M: 55.6 ± 5.2, F: 53.3 ± 5.3	7-d DR − measuring equipment provided.	α -carotene, β - carotene, lycopene,	created 2 databases [1]: raw food only [2]; compensated database to consider cooking losses Standard tables of food composition in Japan (FCT5) and USDA	Serum α -carotene, β - carotene, lycopene	NR	NR
Le Marchand et al. (1994) [135]	Hawaii	Cohort	15	80% M	63.6(54–77)	3-d DR measuring equipment provided	α -carotene, β - carotene, lutein, β - cryptoxanthin, lycopene,	For carotenoids: Mangels et al. The carotenoid content of fruits and vegetables: an evaluation of analytical data	α -carotene, β - carotene, lutein, β - cryptoxanthin, lycopene,	HPLC	12 h
Lin et al. (2010) [136]	Taiwan	Case-control	34 case (COPD); 43 controls	COPD: 21M, 13F; HC: 13M, 30F	COPD: 70.4 ± 9.6; HC: 63.9 ± 5.9	Personal interview; 24 h food recall; semi-quantitative FFQ (68 F&V items − 'cooling', 'neutral' and 'heating' foods)	α -carotene, β - carotene	USDA National Nutrient Database for Standard Reference, release 20	α -carotene, β - carotene, lutein, lycopene	HPLC	Yes, time not given
Liu et al. (1992) [137]	USA	longitudinal	n = 224	100% F	24 h recall group: 23.8 ± 4.8; biochemical ax: 23.6 ± 4.7	FFQ at baseline using visual cues, +24 h dietary recall at baseline, 2mths, 4mths, 6mths	β - carotene	National Cancer Institute	β - carotene	UC	No
Ma et al. (2009) [138]	China	RCT	37	51% M	22–30 yrs	FFQ at baseline and final visit (12wks).	Lutein, B-carotene, retinol equivalents	analysis not described	lutein, B-carotene	HPLC	Yes, overnight
Machefer et al. (2007) [34]	France	Cross sectional	19	100% M	41.4 ± 1.8	7-d DR,	Retinol, β - carotene	analysed using computer dietary analysis Ciqual	B-carotene, retinol	HPLC	NR
Maleksha et al. (2006) [139]	Iran	longitudinal, reproducibility study	131	51M, 80F in text. However, Table 2 shows 49M, 82F	M: 51.2(13.2); F: 49.9(9.8)	12 mths study: 150-item semi-quantitative FFQ x4; 24hr food recalls x12;	B-carotene	nutritionist software V.IV, USDA FCT for most items, Iran FCT for some items	Lutein, zeaxanthin, canthaxanthin, B-cryptoxanthin, lycopene, a-carotene, B-carotene No	HPLC	NR
Mandel et al. (1997) [140]	USA	Cross sectional	42	86% M	61.6 ± 1.2	7-d DR − 3 representative days selected. Analysed with Nutritionist IV interface software	B-carotene	USDA and National Cancer Institute	B-carotene	HPLC	NR
Margetts et al. (1993) [141]	ENGLAND	Cross sectional	1844	42% M	16–64	Short questionnaire included questions on general dietary habits; 7-d WFR	Carotene (not specified)	NR	a-carotene, B-carotene	NR	NR

(*continued on next page*)

Table 1 (*continued*)

Source	Country	Study design	n	Gender	Age	Dietary method + reporting period	Dietary carotenoids assessed	Nutritional database used	Biochemical carotenoids assessed	Biochemical method	Fasting time length
McNaughton et al. (2005) [142]	Australia	RCT	28	39% M	48 ± 10.5	129-item semi-quantitative FFQ at baseline (for previous 6 months); WFR for 2 nonconsecutive days every 2months × 6	α -carotene, β -carotene, lutein, β -cryptoxanthin, lycopene, total carotenoids	US Dep Agriculture supplemented by Nutrition Program, University Queensland	α -carotene, β -carotene, lutein (includes zaexanthin), β - cryptoxanthin, lycopene, total carotenoids	HPLC	Non fasting
Meyerhardt et al. (2005) [143]	USA	Cross sectional	192	NR	Median 55 [29–85]	1× 131-item semi-quantitative FFQ, (previous 3 months).	α -carotene, β -carotene, lutein + zeaxanthin, lycopene, β -cryptoxanthin	USDA supplemented information for some supplements and BF cereals	α -carotene, β -carotene, lutein + zeaxanthin, lycopene, β -cryptoxanthin	HPLC	Y. 39%fasted only
Michaud et al. (1998) [144]	USA	cohort	307	39% M	Mean ± SD M: 55.4 ± 10.5; F: 52.7 ± 7.2	FFQ at baseline and at 12 mths (131-item FFQ completed by men, 126-item FFQ completed by women), period evaluated 12 mths; 1-week diet record x2 over 12 mths,	α -carotene, β -carotene, lutein(+zeaxanthin), lycopene, β -cryptoxanthin	USDA	α -carotene, β -carotene, lutein, lycopene, β -cryptoxanthin	HPLC	UC
Mohammadifard et al. (2011) [39]	Iran	cohort	T1: 123; T2: 101	T2: 64M, 59F; T2: 53M, 48F	Mean SD T1: 40.7 ± 8.4; T2: 41.1 ± 8.2	110 item FFQ designed to assess fruit and veg intake in adults of Isfahan. 1 × 24hr recall. 2 × food records, 3 non-consecutive days (inc 1 weekend day).	None. Just whole fruits and vegetables	National Nutrition & Food Technology Research Institute	B-carotene	HPLC	Fasting overnight
Natarajan et al. (2006) [145,146]	USA	RCT	1013	100% F	NR	153-item, semi-quantitative FFQ, reporting period 3mths, completed at baseline and 12 mths; 4× 24-hr diet recalls, (including 2wkd days and 2 week days) over a 3-wk period at baseline and 12 mths,	Total carotenoids (diet + supplements)	FFQ: USDA CSFII	α -carotene, β -carotene, lutein (+zeaxanthin), lycopene, β -cryptoxanthin	HPLC	Y. NR
Newby et al. (2003) [30]	USA	cross sectional	187	men	53.3 ± 0.4	24 h diet recall + FFQ 40 items and reporting period 1 year	Total carotene index	Multiple risk factor intervention trial lipid research based on USDA	Total carotene	HPLC	12 h fast
Nolan et al. (2007) [147]	Ireland	Cross sectional	828	35% M	20–60	166-item semi-quantitative FFQ reporting period previous 2–3 months	Lutein, zeaxanthin	Food composition data from UK, US and European sources plus recipes/manufacturer information where needed	Lutein, zeaxanthin	HPLC	NR
Neuhouser et al. (2007) [148]	USA	Cross-sectional	413	100% F	Mean. Non-hispanic white 31.6 yr, Hispanic 38.8 yr, Native American 38.7 yr	Interview: section 1 – household pantry inventory with Y/N responses to the presence of specific foods. 5 A DAY for Better Health Questionnaire FFQ	5A DAY fruit and veg serves	NA	α -carotene, β -carotene, lutein + zeaxanthin, lycopene, β -cryptoxanthin	HPLC	Yes. Time NR
Ocké et al. (1997) [149]	The Netherlands	cohort	121	52% M	M:20–60 yrs; F: 20–70 yrs	Dutch EPIC 178-item FFQ, reporting period 1yr, administered baseline, 6 mths, 12 mths (focused on relative validity of baseline FFQ); 24-hr recall interview/ month × 12; quarterly blood collections × 4	β - carotene	Adapted version of 1993 computerised Dutch FCT; weighted mean nutrient composition derived from database of the Dutch National Food Consumption Survey 1987/88.	β - carotene	HPLC	No

Olafsdottir et al. (2006) [150]	Iceland	Cross sectional	53	100% F	36 ± 5 yrs	2 × 24-hr recalls over 1 month; 130-item semi quantitative FFQ, period for 3 months; assisted by portion pictures of 3 portion sizes	β - carotene	National Nutrition Database ISGEM	β - carotene	HPLC	Yes. Time NR
Palli et al. (1999) [151]	Italy	case–control	945	59% M	M: 59.5; F: 57.8	FFQ 181 items asked with aid of an atlas containing pictures of foods and portion sizes, period for 12 months prior	Carotene (not specified)	Italian FCT	carotene (represents alpha, beta and gamma)	HPLC	Yes, Time NR
Pierce et al. (2006) [152]	USA	Randomised trial	2922 (participants were from the WHEL study	100% F	18–70 yrs	Self-reported dietary intake using a set of four 24hr dietary recalls over a 3 week period.	None, whole foods only. Food, juice and supplements	Minnesota Nutritional Data System software (Nutritional Data System version 4.01, 2001 University of Minnesota, Minneapolis, MN	α -carotene, β -carotene, β-cryptoxanthin, lutein + zeaxanthin, lycopene	HPLC	Fasting (unsure of time length)
Pollard et al. (2003) [153]	England	Cross sectional	54	100% F	54.2 yr (range: 51.8–56.7 yrs)	4 day food diary previously completed for the Non-Starch Polysaccharide substudy from the UK Women's Cohort Study. 24 hr recall performed at second time point	β-carotene, carotene equivalents	Dietary assessment package COMP-EAT (Carlson Bengston Consultants Ltd,2001)	β-carotene, lutein, cryptoxanthin and lycopene	HPLC	Overnight fast.
Polsinelli et al. (1998) [154]	USA	Cross sectional	20	100% F	Mean 52.7 yrs (range 45–65 yrs)	7 day food records	Fruit and vegetable intake	Nutritionist IV for Windows software (version 4.0, 1995, First DataBank, The Hearst Corporation,	α -carotene, β -carotene, β-cryptoxanthin, lutein, lycopene	HPLC	Fasted (unsure of time length)
Porrini et al. (1995) [155]	Italy	Cross sectional	38	11 M 33 F	Mean age 27.1 (SD 6.3) yrs	Semi-quantitative FFQ (Fidanza et al., 1994). List of 93 foods most commonly consumed foods in Italy. Followed by 7 day weighed food record.	β-carotene	Nutrient database compiled from food composition tables plus partly published data on cooked foods	β-carotene	HPLC	Overnight fast.
Rao et al. (2007) [156]	Canada	Cross sectional	33	100% F	56.33 ± 0.45 yrs	Seven day FR	lycopene	NutriBase 5 Clinical Edition software (Cybersoft, In., AZ).	lycopene, β-cryptoxanthin, α- & β-carotene, lutein	HPLC	12 h fast
Re et al. (2003) [157]	Britain	Cross sectional	1687	Free living: 632 M, 643 F. Institution: 204 M, 208 F.	(yrs) [64–84]	Four day dietary record (weekdays and weekend days).	Weight/type of tomato products consumed on summed: Raw/ processed Tomato containing products	NR	lycopene (n = 1055)	HPLC	Overnight fast from 22:00 h.
Resnicow et al. (2000) [158]	USA	Cross sectional	1114	28% M	18–87 yrs	Three FFQ's. 1. Seven item F + V FFQ for past month 2. two item measure of no of F + V serves consumed/day. 3. 36-item measure of F + V intake. A subsample (n = 414) also completed a 24hr recall	α -carotene, β -carotene, lutein, cryptoxanthin, lycopene	USDA Nutrition Coordinating Center database	α -carotene, β -carotene, lutein, cryptoxanthin, lycopene	HPLC	UC
Rifas-Shiman et al. (2001) [159]	USA	Longitudinal	160	43%M	16–65 yrs	PrimeScreen (18 items on foods and 7 items on vitamin supplements) and a 131 item semi-quantitative FFQ	β-carotene, lutein/ zeaxanthin	Harvard Nutrient composition database	β-carotene, lutein/ zeaxanthin	UC	UC
Ritenbaugh et al. (1996) [160]	USA	Cross sectional	162	57% M	Females 57.3 ± 11.7 Males 57.5 ± 11.0yrs.	Arizona FFQ, modified from Block's HHHQ.	α -carotene, β -carotene, lutein, lycopene	Block's carotenoid file output. Mangel's data base.	α -carotene, β -carotene, lutein, lycopene	HPLC	UC
Rock et al. (1997) [161]	USA	Cross sectional	109	60% M	21–84 yrs	Fred Hutchinson Cancer Research Centre FFQ based on previous 3 month intake	β - carotene	Minnesota Nutrition Data System nutrient database.	α - carotene, β -carotene, β -cryptoxanthin, lycopene, lutein	HPLC	No. Sample taken ≥ 3hr postprandial

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Table 1 (*continued*)

Source	Country	Study design	n	Gender	Age	Dietary method + reporting period	Dietary carotenoids assessed	Nutritional database used	Biochemical carotenoids assessed	Biochemical method	Fasting time length
Rock et al. (1999) [162]	USA	Cross sectional	1042	39% M	37.8% (18–34 yrs), 44.5% (35–54 yrs), 17.7% (55 + yrs)	Health Habits and History Questionnaire (FFQ)100 items with 16 items fruit, 19 vegetables + 7 d food diary	α-carotene, β-carotene, β-cryptoxanthin, lycopene, lutein + zeaxanthin	University of Minnesota's Nutrient Data System.	α-carotene, β-carotene, β-cryptoxanthin, lycopene, lutein, zeaxanthin	HPLC	6 h fast
Rock et al. (2001) [163]	USA	RCT	53 (27 in intervention group and 26 in control group	100%	27.8 ± 0.6 yrs (mean ± SD). Range 19–45 yrs.	Self-administered FFQ with a reference period of 'over the past yr', consisted of 122 food items, 19 adjustment questions on food purchasing and preparation and summary questions on usual intake of F + V.	α-carotene, β-carotene, β-cryptoxanthin, lutein/zeaxanthin, lycopene, total	University of Minnesota (Version 2.92, 1996,.	α-carotene, β-carotene, β-cryptoxanthin, lutein/zeaxanthin, lycopene	HPLC	NR
Rock et al. (2002) [164]	USA	Cross sectional	2786 (1368 in cohort)	39% M	Cross-section: 44 ± 16 yrs (range 18–92 yrs), Cohort: 45 ± 16 yrs (range 18–91 yrs)	Self-administered FFQ with reference period of 'over the past month'	Lutein + zeaxanthin	Minnesota Nutrition Coordinating Centre (NCC) nutrient database (Minneapolis)	α-carotene, β-carotene, β-cryptoxanthin, lutein, zeaxanthin, lycopene	HPLC	Fasted, unsure of time
Romieu et al. (1990) [165]	USA	Cross-section	370		NR –	semi-quantitative FFQ (116 food items) Frequency of consumption over the past yr.	Food high in carotenoids	Computed using empirical weights?	β-carotene	HPLC	Non-fasted
Romieu et al. (1999) [166]	Mexico	Cohort	110	All female	Mean(SD) 35.7(9.6) years, range 15–54 years	FFQ developed using the methodology described by Willett et al. and included a matrix listing of 116 food items (relevant to Mexican people) & 10 frequencies of consumption. The FFQ was administered at baseline and at 1 year. four 24 h recalls every 3 months for a total of 16 24 h recalls per participant over the 1 year study.	α-carotene, β-carotene, lycopene, lutein + zeaxanthin, total carotene	USDA complemented by the National Institute of Nutrition in Mexico database.	No Plasma α- carotene, β-carotene, lycopene, lutein, zeaxanthin	NR	Non fasting
Russel-Briefel et al. (1985) [29]	USA	Baseline of intervention	187 only 35 had bloods	male	Age 53.3 ± 0.4 weight (lb) 191 2.1	24 h recall + FFQ of 40 items reporting period 1 yr info on supplements collected in addition	Total carotene	Multiple risk factor intervention Trial lipid research clinics food analysis tape based on USDA	Total plasma carotenoids		12 h
Ryden et al. (2012) [167]	Sweden	Cross sectional	284	49% M	Male: 57 [52–62] yrs, female: 57 [51–63] yrs	FFQ with 92 country specific food items. Also included questions about regular vitamin supplementation (±3 times/week) and alcohol intake also assessed.	Intake of high carotenoid F + V	Not specified.	β-cryptoxanthine, α-carotene, β-carotene, lutein (+zeaxanthin), lycopene	HPLC	Fasted, unsure of time
Stallone et al. (1997) [168]	England	Cross sectional	865	53% M	Male: 50.0 ± 6.0 yrs (range 39–61), Female: 50.0 ± 6.0yrs (range 39–61 yrs)	Open-ended estimated seven-day diet diary with 7 time periods: before breakfast, breakfast, mid-morning, lunch, tea, evening meal, later evening.	Carotene (as total β-carotene activity)	Computerised system developed for the Whitehall II dietary data. based on the 4th and 5th editions of McCance and Widdowson and supplementary tables	Plasma β-carotene	HPLC	4- 8 h
Sasaki et al. (2000) [169]	Japan	Cross sectional	86	49% M	Male: 41.9 ± 8.3 (range 31–58),		α-carotene, β-carotene and total carotene	Intakes calculated using an ad-hoc		HPLC	Non-fasted

					Female: 43.2 ± 10.6 (range 24–67)	Diet history questionnaire (prev month).		computer algorithm developed to analyse the questionnaire	Serum α-carotene, β-carotene and total carotene		
Satia et al. (2009) [170]	USA	Cross sectional	164 (81 White, 83 African American (AA)	47% M	Mean (SD): White: 32.5 (7.9) yrs. African-American: 30.9 (7.9) yrs.	**Antioxidant Nutrient Questionnaire:** 92 item self administered questionnaire. Included 80 foods. **Dietary recalls:** 4 unannounced telephone administered 24-hr recalls. **Dietary supp inventory:**	α- carotene, β-carotene, β-cryptoxanthin, lutein + zeaxanthin, lycopene	Nutrition Data System software (version 5.0.35, 2006, University of Minnesota, Minneapolis)	α- carotene, β-cryptoxanthin, lutein + zeaxanthin, lycopene	UC	Semi-fasted (6 h)
Schroder et al. (2001) [40]	Spain	Cross sectional	44	30% M	Mean ± SD: 30.7 ± 10.4 yrs	**1) 3d EFR** weekdays + weekends. **2)** 72 h recall questionnaire with food list of 90 foods A subset (n = 19) completed a 2nd 72 h recall. **3)** FFQ administered twice at 6 week interval. 157 food items A subset (n = 29) repeated the FFQ	β-carotene	Diet Analysis Nutritionist IV (N squared computing, San Bruno, SA, USA)	β-carotene (Blood samples obtained once in 19 subjects and twice, one month apart, in another 24 participants.	HPLC	Fasted (unsure of time length)
Shai et al. (2005) [171]	Israel	Cohort	161	78% M	Mean ± SE: 50.0 ± 0.5 yrs	**1) Three** semi-quantitative FFQ at 1 month, 6 months and 13 months. **2)** Six 24hr recall interviews on random workdays using a modified USDA 24hr recall. At 1,3,6,8,11 and 13 months	β-carotene	NR	β-carotene at 1 and 6 months	Spectrophotometrically	Fasted overnight
Signorello et al. (2010) [172]	USA	Cross sectional	255 (125 African American (AA), 130 non-Hispanic whites)	AA: 63 F, 62 M. Whites: 64 F, 66 M.	40+ −59 yrs: AA: 25 F, 32 M. White: 18 F, 23 M. 50–59 yrs: AA: 20 F, 17 M. Whites: 22 F, 20 M. 60 + yrs AA: 18 F, 13 M. Whites: 24 F, 23 M.	89-item FFQ administered through a computer-assisted in-person interview. Nine items are specific to fruits or fruit juices, 13 are specific to vegetables.	α- carotene, β-carotene, β-cryptoxanthin, lutein + zeaxanthin, lycopene	nutrient databases developed for the SCCS that were based on dietary patterns in the southern US.	α- carotene, β-carotene, β-cryptoxanthin, lutein + zeaxanthin, lycopene	HPLC	Non-fasted
Roidt et al. (1988) [173]	USA	Cross sectional	302	57% M	Mean (SD): 58.5 (4.6) yrs. (Range 48–68 yrs)	FFQ with 71 food items assessing frequency of intake over the past yr.	β-carotene,	UC	α-carotene and β-carotene	Reverse phase HPLC	NR
Sauvageot et al. (2013) [174]	Luxembourg	Cross Sectional	922	51%M	M/F 18–29yrs − 78/82 30–49yrs − 207/193 50–69yrs − 185/177	Semi quantitative FFQ, 73 items over the past 3 months, photos to guide portion size, in of on supplement use also collected	β-carotene + Fruit and vegetable	SU.VI.MAX	β-carotene	UC	8 h fast
Shiraishi et al. (2013) [35]	Japan	Cross sectional	95	100% F	Mean ± SD 35.3 ± 4.9	Diet History Questionnaire 22 page reporting period prev month, in of on supplements also obtained	β-carotene	Japanese food composition tables	β-carotene	HPLC	UC
Stryker et al. (1990) [175]	USA	Cross sectional	330	42% M	Mean ± SD: 35.4 ± 13.5 F; 35.8 ± 12.3 M	Self-administered FFQ - 116 food categories including major food sources of preformed Vit A and carotene. Additional frequency and type of vitamin supplementation	Carotene (carotenoid precursors of Vit A	USDA	a-carotene, b-carotene, lycopene	HPLC	Non-fasting

(*continued on next page*)

Table 1 (*continued*)

Source	Country	Study design	n	Gender	Age	Dietary method + reporting period	Dietary carotenoids assessed	Nutritional database used	Biochemical carotenoids assessed	Biochemical method	Fasting time length
Su et al. (2006) [176]	USA	Cross sectional	17,688	47% M	18–45 yrs Mean ± SD: Females 31.0 ± 7.9; Males 30.8 ± 7.9; 55 + yrs Mean ± SD: Females 71.1 ± 9.7; Males 70.4 ± 9.4	24 h recall collected through automated dietary data collection system. Additional questions asked about use of vitamin and mineral supplements.	Salad, Vegetable	UC	a-carotene, b-carotene, lycopene	HPLC	Unclear
Svendsen et al. (2007) [177]	Norway	RCT	138	75% M	21–72 yrs; Mean ± SD 48.2 ± 9.0	Dietary interview based on 174-item FFQ conducted at baseline and 3 months (previous 3 months). 28 vegetable items, 29 fruits and berries.	b-carotene, vegetable, fruits/juices/berries	Norwegian food composition tables	a-carotene, b-carotene, lycopene, lutein, zeaxanthin, b-cryptoxanthin	HPLC	Overnight fasting − 10 h
Talegawkar et al. (2008) [178]	USA	Cross sectional	402	39% M	≥34 yrs; Mean ± SE F 61.5 ± 0.6; M 60.2 ± 0.8	24 h recalls conducted over phone in order to design a representative FFQ for use in this study. Short 158-item FFQ used at baseline, 4 × 24 h recalls, one month apart and long 283-item FFQ administered one week after final recall. Included use of supplements.	a-carotene, total b-carotene, dietary b-carotene, lycopene, b-cryptoxanthin, combined lutein/ zeaxanthin.	NR	a-carotene, b-carotene, lycopene, b-cryptoxanthin, combined lutein/ zeaxanthin.	HPLC	Fasting − 10 h
Tangney et al. (2004) [179]	USA	Cross sectional	59	42% M	Mean ± SD: 73.8 ± 5.8	156-item FFQ completed at baseline and 12–14 months after. Home-based 24 h recalls administered every 2 months over the 12–14 month period.	total b-carotene, dietary b-carotene, a-carotene, b-cryptoxanthin, lutein + zeaxanthin, lycopene	Harvard nutrient database - updated continually using USDA nutrient database.	b-carotene, a-carotene, b-cryptoxanthin, lutein + zeaxanthin, lycopene	HPLC	Fasting
Tan-Un et al. (2004) [180]	China	Case-control	72	NR	Mean ± SD asthmatics: 39 ± 15.9; non-asthmatics: 35 ± 10.0	Telephone administered semiquantitative 30-item FFQ to assess intake over previous 12 months.	dietary carotene	Published food tables from Hong Kong and China.	b-carotene	Macro- and micro-method modified from Emmerie-Engel method.	Non-fasting
Tarwadi et al. (2008) [181]	India	Case-control	240	49% M	50–75 yrs	Structured 94-item FFQ including seasonal fruit and vegetable intake.	b-carotene	Indian food composition tables (Nutritive value of Indian foods - National Institute of Nutrition, Indian Council of Medical Research)	plasma b-carotene	Spectrophotometric and fluorescence-based estimations	Fasting
Thomson et al. (2007) [182]	USA	Cross sectional	207	100% F	18-70 yrs; Mean ± SD 53.5 ± 9.1	153-item FFQ administered at baseline. Supplement intake was also recorded.	a-carotene, b-carotene, lutein + zeaxanthin, lycopene and b-cryptoxanthin, supplemental b-carotene	CSFII USDA	a-carotene, b-carotene, lutein + zeaxanthin, lycopene and b-cryptoxanthin	HPLC	Fasting
Toft et al. (2008) [183]	Denmark	Cross sectional	264	47% M	Mean(Range): 48.4(38–63)	28-day diet history with a checklist to conclude and a 198-item semi-quantitative FFQ assessing food intake over the past month.	b-carotene, fruits and vegetables	Danish Food Composition Databank (version 6)	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein, zeaxanthin	HPLC	Fasting - 8hr
Torronen et al. (1996) [184]	Finland	RCT	38	100% F	Range: 20–53 yrs; Mean: 30 yrs	Intakes of b-carotene were assessed by a 1-month FFQ. Energy and other nutrients assessed by 4-day food record.	b-carotene	Finnish foods database	b-carotene	HPLC	Overnight fast
Tucker et al. (1999) [185,186]	USA	Cross sectional	[1] 638 [2]; 547	[1] 408 F 230 M [2]; 346 F 201 M	>65 yrs	Semi quantitative 126-item food-frequency questionnaire including vitamin supplements.	a-carotene, total b-carotene, dietary b-carotene, b-cryptoxanthin, lycopene,	USDA	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	HPLC	Non-fasting

							lutein + zeaxanthin & fruit and veg intake				
VandenLangenberg et al. (1996) [50]	USA	Cross sectional	400	45% M	>43 yrs	100-item FFQ (Block-NCI Health Habits and History Questionnaire HHHQ) intake over the previous 12 months.	[1] a-carotene, b-carotene, b-cryptoxanthin, a-cryptoxanthin, lycopene, lutein + zeaxanthin [2]; all but a-cryptoxanthin	National Cancer Institute (NCI) and combined USDA-NCI.	[1] a-carotene, b-carotene, b-cryptoxanthin, a-cryptoxanthin, lycopene, lutein + zeaxanthin; total carotenes [2] all but a-cryptoxanthin	HPLC	Non-fasting
Vioque et al. (2007) [187]	Spain	Cross sectional	545	46% M	Mean: 73.5 yrs	Semi-quantitative 135-item FFQ (modified from Harvard questionnaire) including vitamin supplements.	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	USDA-NCI carotenoid database.	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	HPLC	85% were non-fasted
Vioque et al. (2013) [36]	Spain	Cross sectional	740	100% F	<29yrs 336, 30–24 285, >35,119	Semi-quantitative 135-item FFQ (modified from Harvard questionnaire) including vitamin supplements.	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	USDA complimented with Spanish sources	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	HPLC	Nonfasting
Walqvist et al. (1999) [188]	Australia	RCT	224	62% M	30–75 yrs; Mean 56 yrs	FFQ administered at baseline and 12 months assessing intake over the previous 12 months.	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	Carotenoid food composition database USDA-NCI	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	HPLC	Fasting
Wallstrom et al. (2001) [189]	Sweden	Cross sectional	529	48% M	46–67 yrs	Modified diet history combining quantitative and semiquantitative measures. Part 1 recorded cooked meals, beverages supplements during 7 consecutive days; part 2 was a 168-item questionnaire on foods consumed regularly (other than cooked foods) during the past yr.	b-carotene	Swedish national food administration food database.	b-carotene (food derived, total including supplements)	HPLC	Non-fasting
Wawrzyniak et al. (2013) [37]	Sweden	Cross sectional	159	100% F	56–75 yrs	FFQ 96 item reporting period prev yr	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin + Fruits and vegetables	Various Swedish sources	a-carotene, b-carotene, b-cryptoxanthin, lycopene, lutein + zeaxanthin	HPLC	Fasting
Willett et al. (1983) [190]	USA	RCT	58	Male and female	20–60 yrs	FFQ – 99 items with specified portion size. Supplementary questions about margarine, cooking oil, breakfast cereal and vitamin supplements. Reporting period NR	Carotene, vitamin E and Vitamin A	USDA carotenoids 1975	Plasma carotene	HPLC	Fasting
Wolters et al. (2006) [191]	Germany	Cross sectional	178	100% F	60–70 yrs (mean 63.2 ± 2.73)	3 day diet record	β carotene	German food code	β carotene	HPLC	Overnight
Yong et al. (1994) [51]	USA	Cross sectional	98		Mean age 28.6 ± 5.1	7 consecutive days of Diet records and FFQ -Health Habits and History Questionnaire 100 items reporting period 1 yr, with portions rated as S,M or L(12 fruits and juices, 17 vegetables	α carotene, β carotene, β cryptoxanthin lutein and zeaxanthin and lycopene	USDA	α carotene, β carotene, β cryptoxanthin lutein and zeaxanthin and lycopene	HPLC	Fasting
Ylonen et al. (2003) [192]	Finland	Cross sectional	182	Men 101 Women 81	Mean age 53 ± 1	3 day estimated food record (2 weekdays + 1 weekend day). Estimated food portion by picture booklet	α carotene, β carotene and lycopene	NUTNET developed by the National Public Health Institute, Helsinki	α carotene, β carotene and lycopene	HPLC	Fasting no other details reported

Unless otherwise specified, reported as mean ± SD, F = female, M = Male, BMI reported as kg/m2, HPLC = High Performance Liquid Chromatography, FFQ = food frequency questionnaire, FR = food record, NR = not reported, UC Unclear.

Table 2
Outcomes of included studies.

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
AAA Epic group, (1997) [43]	**Diet history:** β - carotene Mean(SD) (mg/dl) total 4418 (3329); M 4210 (2995)F 4584 **24 h recall:** β - carotene Mean(SD) (mg/dl) total - 2976 (1719); M 4210 (2995); F 3120 (1710);	Mean(SD) (mg/dl) α-carotene total 5.2 (4.2); M 3.7 (2.3); F 6.3 (4.9); β-carotene total 24.2 (15.7); M 15.2 (7.7); F 31.2 (16.7); cryptoxanthin total 17.9 (9.6); M 14.3 (6.8); F20.7 (10.5); lutein-zeaxanthin total 17.0 (7.0); M 15.8 (6.7); F 17.9 (7.3); lycopene 30.9 (16.6); M 27.1 (9.8); F 33.9 (19.9); Total carotenoids total 95.1 (42.2); M 75.6 (26.8); F 110.1 (46.0);	**Diet history:** b-carotene (M&F) 0.33; M 0.27; F 0.40; smokers 0.04; non-smokers 0.39; total carotenoids (M&F) 0.27; M 0.15; F 0.35; smokers 0.03; non-smokers 0.32; **24 h recall:** b-carotene (M&F) 0.42; M 0.42; F 0.44; smokers 0.37; non-smokers 0.44; total carotenoids (M&F) 0.28; M 0.19; F 0.32; smokers 0.22; non-smokers 0.31.	Dietary fat not assessed. Unclear which are significant and which are not.
Alberti-Fidanza et al. (1998) [62]	**Weighed record:** β-carotene (μg) 2059.2 ± 1176.3; **diet history:** β-carotene (μg) 3325.0 ± 2004.2; **Chemical analysis:** β-carotene (μg) 961.5 ± 814.7;	β-carotene (μmol/L) 0.60 ± 0.33;	No significant correlations between dietary intake and plasma concentrations.	
Al-Delaimy et al. (2005) [44]	NR	Mean(SE) μmol/L: **M** α-carotene 0.12 (0.01); β-carotene 0.36 (0.01); β-cryptoxanthin 0.23 (0.01); lutein 0.38 (0.005); zeaxanthin 0.09 (0.001); lycopene 0.74 (0.01); total carotenoids 1.94 (0.023); F α-carotene 0.20 (0.005); β -carotene 0.54 (0.012); β-cryptoxanthin 0.34 (0.007); lutein 0.44 (0.006); zeaxanthin 0.09 (0.001); lycopene 0.71 (0.01); total carotenoids 2.35 (0.03)	**Fruits and vegetables from FQ:** α -carotene 0.09; β-carotene 0.17; cryptoxanthin 0.46; lutein 0.38; zeaxanthin 0.36; lycopene 0.24; total carotenoids 0.38; **fruits and veg from 24HDR:** α -carotene 0.10; β -carotene 0.15; cryptoxanthin 0.39; lutein 0.31; zeaxanthin 0.32; lycopene 0.14; total carotenoids 0.30; **fruits from FQ:** α -carotene NS; β -carotene 0.11; cryptoxanthin 0.52; lutein 0.37; zeaxanthin 0.37; lycopene 0.22; total carotenoids 0.36; **fruits from 24HDR:** α -carotene 0.06; β -carotene 0.11; cryptoxanthin 0.39; lutein 0.25; zeaxanthin 0.26; lycopene 0.10; total carotenoids 0.25; **veg from FQ:** α -carotene 0.16; β -carotene 0.21; cryptoxanthin 0.26; lutein 0.30; zeaxanthin 0.26; lycopene 0.19; total carotenoids 0.31; **veg from 24HDR:** α -carotene 0.13; β -carotene 0.16; cryptoxanthin 0.19; lutein 0.23; zeaxanthin 0.22; lycopene 0.12; total carotenoids 0.21.	Country specific questionnaires only validated within country, not between.
Allen et al. (2003) [63]	Mean intake of lycopene at baseline was 6.4 mg/day and after 2 weeks 0.31 mg/day.	Plasma concentrations (mmol/L; Mean ± SE) at baseline (total group and week 6 in the three intervention groups (sauce/soup/juice). **Baseline:** α-carotene 0.12 ± 0.01; β carotene 0.45 ± 0.06; cryptoxanthin 0.37 ± 0.04; lutein 0.22 ± 0.02; zeaxanthin 0.06 ± 0.004; lycopene 1.06 ± 0.04; **6 weeks:** α -carotene 0.12 ± 0.03/0.11 ± 0.01/0.22 ± 0.03; β -carotene 0.53 ± 0.09/0.43 ± 0.06/0.85 ± 0.24; cryptoxanthin 0.47 ± 0.13/0.35 ± 0.06/0.30 ± 0.08; lutein 0.20 ± 0.02/0.25 ± 0.02/0.25 ± 0.03; zeaxanthin 0.12 ± 0.01/0.11 ± 0.01/0.11 ± 0.01. lycopene 1.68 ± 0.07/1.04 ± 0.05/0.98 ± 0.05;	Correlation of dietary lycopene and plasma lycopene: **Baseline** $r = 0.578$; $p < 0.0005$; After 3 week **(Week 6)** diet intervention $r = 0.499$; $p < 0.005$	Poor reporting of dietary outcomes.
Anderson et al. (2005) [64]	Mean(SD), weighed record (WR) and 180-item FFQ = g/day. 27-item FFQ = times/day.	Mean(SD) (μmol/L): α-carotene 0.09(0.07); β-carotene 0.5(0.23)	**WR:** veg and α -carotene (0.52); Veg and lutein (0.21) **180-item FFQ:** Veg and a-carotene (0.39);	Combined correlations reported for supplement and non-supplement users. Small sample size, men only.

	Fruit: WR 109(107); 180-item FFQ 128(107); 27-item FFQ 0.9(0.6); **Vegetable:** WR 108(59); 180-item FFQ 115(70); 27-item FFQ 0.8(0.4)	Lutein 0.17(0.06); Zeaxanthin 0.04(0.02); Lycopene 0.75(0.38);	**27-item FFQ:** Veg and a-carotene (0.35). No significant correlations for fruit and plasma concentrations.	
Arab et al. (2011) [65]	Mean intake (μg/day) in african americans (AA) and whites (W) **24HDR:** α -carotene (AA) 310; (W) 71; β -carotene (AA) 1420; (W) 2027. **c**ryptoxanthin: (AA) 110; (W) 120; Lutein + zeaxanthin: (AA) 3420; (W) 4500; lycopene: (AA) 3170; (W) 6320; **DHQ:** α carotene (AA) 406; (W) 557; β -carotene (AA) 2620; (W) 3152. cryptoxanthin (AA) 152; (W) 132; lutein + zeaxanthin (AA) 2316 (W) 2606; lycopene (AA) 4924; (W) 5659;	**African Americans: Mean μmol/L** − α -carotene 0.06; β -carotene 0.28; cryptoxanthin 0.18; lutein + zeaxanthin 0.25; lycopene 0.60; **Whites: Mean μmol/L** − α carotene 0.07; β -carotene 0.31; cryptoxanthin 0.16; lutein + zeaxanthin 0.27; lycopene 0.57;	**Whites:** a-carotene 0.27; β -carotene 0.38. b-cryptoxanthin 0.51; lutein + zeaxanthin 0.48; lycopene 0.13; Incomplete reporting of significant correlations within groups, only other significances reported is between groups (whites and african americans). In 24HDR, there was a significant difference between AA and W for all carotenoids except lycopene and for DHQ, only lutein + zeaxanthin and b-carotene showed a significant difference between AA and W.	Analysis contains data from subjects who consumed supplements.
Arnaud et al. (2001) [31]	Mean total carotenoids (μg) Period 1: 1028; Period 2: 779; Period 3: 586; Period 4: 1395	Mean ± SD or Median(range) carotenoids (nmol/L) **Period 1:** α-carotene 51(2−466); β-carotene 95(13−1088); cryptoxanthin 93 ± 67; lutein-zeaxanthin 563(163−3503); lycopene 348(41−2130); total carotenoids 1427 ± 702; **Period 2:** α -carotene 24(2−192); β -carotene 106(6−1011); cryptoxanthin 117 ± 91; lutein-zeaxanthin 494(128−7766); lycopene 74(4−492); total carotenoids 1206 ± 978; **Period 3:** α -carotene 32(6−155); β carotene 60(6−415); cryptoxanthin 132 ± 85; lutein-zeaxanthin 486(156−2228); lycopene 120(2−1713); total carotenoids 1037 ± 554; **Period 4:**; α -carotene 43(6−685); β carotene 90(13−909); cryptoxanthin 112 ± 85; lutein-zeaxanthin 492(163−3459); lycopene 310(19−2533); total carotenoids 1243 ± 868	Carotenoids expressed as μmol/L **Period 1 (March-April):** r = 0.148 (p = 0.048); **Period 3 (October):** r = 0.200 (p = 0.017). Plasma total carotenoids expressed as μmol/mmol cholesterol **Period 3:** r = 0.216 (p = 0.010).	Sample not representative of healthy population and included men only. FFQ not referenced or validated.
Bermudez et al. (2005) [66]	Mean ± SE μg/day: **α-carotene** Hispanic men (HM) 685 ± 60; hispanic women (HW) 786 ± 51; Non-Hispanic men (NHM) 981 ± 109; Non-hispanic women (NHW) 908 ± 87; **β-carotene** HM 3281 ± 189; HW 635 ± 214; NHM 4091 ± 338; NHW 3815 ± 368; **cryptoxanthin** HM 152 ± 10; HW 170 ± 8; NHM 164 ± 24; NHW 126 ± 19; **lutein** + **zeaxanthin** HM 1470 ± 96; HW 1556 ± 80; NHM 2882 ± 341; NHW 2251 ± 273; **lycopene** HM 6067 ± 297; HW 5352 ± 249; NHM 5793 ± 578; NHW 4638 ± 463	Mean ± SE nmol/L: **α -carotene** HM 101 ± 0.05; HW 129 ± 0.04; NHM 72 ± 0.09; NHW 78 ± 0.07; **β -carotene** HM 227 ± 0.05; HW 301 ± 0.04; NHM 261 ± 0.09; NHW 291 ± 0.07; **cryptoxanthin** HM 89 ± 0.05; HW 114 ± 0.04; NHM 93 ± 0.10; NHW 106 ± 0.08; **lutein** HM 212 ± 0.04; HW 210 ± 0.03; NHM 185 ± 0.09; NHW 189 ± 0.07; **zeaxanthin** HM 68 ± 0.04; HW 67 ± 0.03; NHM 58 ± 0.10; NHW 65 ± 0.08; **lycopene** HM 448 ± 0.03; HW 461 ± 0.03; NHM 345 ± 0.09; NHW 346 ± 0.07	Total carotenoid intake with **α** -carotene 0.23 ± 0.03; β -carotene 0.24 ± 0.04; cryptoxanthin 0.29 ± 0.03; lutein + zeaxanthin 0.16 ± 0.04; lycopene 0.09 ± 0.03 ($p < 0.001$ for all except lycopene $p < 0.01$).	Results reported combined for supplement and non-supplement users. Non-validated FFQ.

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Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
Bernstien et al. (2002) [67]	**Mean ± SE (μg/day) Baseline/Follow-up/Change: Nutrition group:** α carotene 454 ± 331/1003 ± 803/ 549 ± 126; β-carotene 4046 ± 2072/ 6454 ± 3012/2408 ± 495; cryptoxanthin 91.3 ± 76.1/148.5 ± 89.5/ 57.2 ± 15.1; lutein 2720 ± 2529/ 4240 ± 4739/1521 ± 741; lycopene 1347 ± 753.4/2291 ± 1290/944 ± 199; **Exercise group** α -carotene 795 ± 718/ 790 ± 680/-5.7 ± 130; β −carotene 4586 ± 2691/4689 ± 2485/103 ± 490; cryptoxanthin 132.5 ± 93.1/ 139.1 ± 70.1/6.6 ± 14.8; lutein 2330 ± 2178/2247 ± 2458/-84 ± 454; lycopene 1551 ± 1031/ 1828 ± 1031 277 ± 156	**Mean ± SE (μg/L) Baseline/Follow-up/Change:** Nutrition group: α -carotene 0.33 ± 2.50/ 0.42 ± 3.03/0.09 ± 0.39; β -carotene (umol/L) 0.8 ± 0.6/1.0 ± 0.7/0.2 ± 0.10; cryptoxanthin 1.01 ± 3.05/1.09 ± 3.82/0.08 ± 0.28; lutein 1.94 ± 11.2/2.27 ± 10.5/0.33 ± 1.80; lycopene 0.72 ± 5.35/0.76 ± 4.45/0.04 ± 0.58; total carotenoids 11.8 ± 37.6/12.9 ± 47.9/ 1.2 ± 4.35;**Exercise group** α -carotene 0.38 ± 2.57/ 0.33 ± 2.52/0.01 ± 0.34; β -carotene (umol/L) 0.8 ± 0.6/0.9 ± 0.6/0.1 ± 0.07 cryptoxanthin 0.96 ± 1.75/0.99 ± 1.88/0.03 ± 0.24; lutein 2.15 ± 13.0/2.42 ± 16.8/0.27 ± 2.00; lycopene 0.73 ± 4.72/0.77 ± 5.52/0.04 ± 0.60; total carotenoids 12.7 ± 54.6/13.1 ± 55.8/0.36 ± 5.04;	Baseline correlations between intake and α -carotene ($r = 0.29$; $p = 0.08$) and β -carotene ($r = 0.33$; $p = 0.08$). Changes in intake of a-carotene and b-carotene significantly correlated with plasma a-carotene ($r = 0.33$; $p = 0.09$) and b-carotene ($r = 0.33$; $p = 0.020$).	Although method of plasma carotenoid analysis was not reported.
Bingham et al. (1995) [68–71]	5 quintiles: Mean ± SE carotene g/day − 1st (lowest) quintile 3.5 ± 0.3; 2nd 3.7 ± 0.4; 3rd 3.1 ± 0.3; 4th 3.7 ± 0.4; 5th (highest) 3.5 ± 0.4	Reported in Bingham 1995: Mean ± SE μmol/L: **α-carotene** 1st: 0.12 ± 0.02; 2nd: 0.13 ± 0.02; 3rd: 0.11 ± 0.01; 4th: 0.11 ± 0.02; 5th: 0.07 ± 0.01, **β-carotene** 1st: 0.57 ± 0.06; 2nd: 0.62 ± 0.07; 3rd: 0.50 ± 0.07; 4th: 0.49 ± 0.07; 5th 0.35 ± 0.04; **cis-carotene** 1st: 0.05 ± 0.005; 2nd: 0.05 ± 0.004; 3rd: 0.05 ± 0.006; 4th: 0.04 ± 0.005; 5th: 0.04 ± 0.003; **cryptoxanthin** 1st: 0.26 ± 0.02; 2nd: 0.28 ± 0.04; 3rd: 0.29 ± 0.03; 4th: 0.30 ± 0.06; 5th: 0.24 ± 0.04; **lutein** 1st: 0.45 ± 0.03; 2nd: 0.47 ± 0.04; 3rd: 0.39 ± 0.03; 4th: 0.44 ± 0.05; 5th 0.32 ± 0.03; **lycopene** 1st: 0.33 ± 0.02; 2nd: 0.36 ± 0.04; 3rd: 0.28 ± 0.03; 4th: 0.30 ± 0.06; 5th: 0.24 ± 0.04; Reported in Bingham 1997(26 suppl 1): Mean ± SD carotene (mg): 16-day weighed records 3.4 ± 1.9; FFQ 5.1 ± 3.2; 24-h recall 3.5 ± 3.7; 7-day estimated food record (food diary) 3.2 ± 1.8	1995 results: dietary b-carotene equivalents and plasma β carotene ($r = 0.48$); dietary β carotene equivalents and plasma a-carotene ($r = 0.62$). P-values NR. 1997(6) results: correlations between dietary carotene and plasma b-carotene: weighed records $r = 0.46$; checklist $r = 0.30$; checklist with portions $r = 0.27$; oxford FFQ $r = 0.15$; cambridge FFQ $r = 0.04$; unstructured 24hr recall $r = 0.09$; structured 24hr recall $r = 0.00$.	Few dietary carotenoids reported. Female only sample.
Block et al. (2001) [24]	Fruit and vegetable frequency (times/ day) - Mean ± SD: 2.9 ± 1.9	Mean ± SD, (μg/dl): β-carotene:13.5 ± 11.4; cryptoxanthin: 11.2 ± 9.1; total carotenoids: 80.6 ± 34.0	β -carotene (0.35; $p = 0.001$); cryptoxanthin (0.43; $p = 0.0001$); total carotenoids (0.34; $p = 0.001$).	Men only
Bodner et al. (1998) [72]	Mean ± SD (μg/day): β-carotene F: 2051.3 ± 1146.4; M: 2014.0 ± 1272.8; total β -carotene F: 2065.9 ± 1165.1; M: 2024.4 ± 1272.4	Mean β -carotene (μmol/L): Females 0.5 ± 0.4; Males: 0.4 ± 0.4	β -carotene (including supplement users) ($r = 0.24$; $p < 0.001$); excluding supplement users ($r = 0.22$; $p < 0.001$).	Poorly described dietary assessment methods
Boeing at al (1997) [74]	**Mean dietary carotenoid intake across quintiles of 24 h recall** (mg/ day): Quintile [1]: 1.6 ± 0.3 [2]: 2.2 ± 0.1 [3]: 2.7 ± 0.2 [4]: 3.6 ± 0.3; [5]: 5.8 ± 1.7. **Mean intake from 24 h recalls across quintiles of FFQ** (mg/ day): [1]: 2.8 ± 1.8 [2]: 2.9 ± 1.9 [3]: 2.9 ± 0.9 [4]: 3.2 ± 1.5 [5]: 4.2 ± 1.8.	**Mean plasma concentrations across quintiles of 24 h recall** (μg/ml) [1]: 344 ± 146 [2]: 386 ± 339 [3]: 363 ± 197 [4]: 610 ± 349 [5]: 753 ± 478; **Mean intake from 24 h recalls across quintiles of FFQ** [1]: 394 ± 229 [2]: 358 ± 239 [3]: 491 ± 362 [4]: 595 ± 500; [5]: 631 ± 349	Plasma carotenoids/FFQ (0.35) - no p-value reported	Unclear if blood collection was fasting, few carotenoids measured, dietary fat not accounted for.
Bogers et al. (2003; 2004) [45,75]	**Results from 2003:** Mean intake by either summing [1] all items in a category i.e. fruit [2] question for that	**Results from 2003:** Plasma concentrations at 10th, 25th, 50th, 75th and 90th %iles (μmol/L): α-carotene: 10th 0.06; 25th 0.09; 50th 0.13; 75th	**Results from 2003: Total vegetables** [1]**:** α -carotene; 0.20 (0.01); b-carotene 0.14 (0.08); lutein 0.25 (0.00); total carotenoids	No adjustment for demographics, lipids/fat intake. 1-month reporting period dietary assessment

	category (g/day) [1]: total veg 264 ± 123; cooked veg 204 ± 94; raw veg 60 ± 66; fruit 195 ± 128; fruit juice 79 ± 95; [2]: total veg 151 ± 69; cooked veg 110 ± 51; raw veg 41 ± 38; fruit 156 ± 116; fruit juice 67 ± 84. **Results from 2004:** Mean ± SD (servings per day) Baseline/1month − intervention group: Total veg 3.4 ± 1.7/4.6 ± 1.4; Total fruits 1.9 ± 1.1/2.9 ± 1.2; Citrus fruits 0.4 ± 0.5/0.7 ± 0.6; Total fruits and vegetables 5.3 ± 2.3/7.5 ± 2.0	0.19; 90th 0.24; β-carotene 10th 0.21; 25th 0.29; 50th 0.45; 75th 0.65; 90th 1.02; b-cryptoxanthin 10th 0.30; 25th 0.39; 50th 0.51; 75th 0.71; 90th 1.04; lutein 10th 0.24; 25th 0.29; 50th 0.38; 75th 0.48; 90th 0.61; lycopene 10th 0.14; 25th 0.22; 50th 0.26; 75th 0.36; 90th 0.43; total carotenoids 10th 1.24; 25th 1.49; 50th 1.90; 75th 2.20; 90th 2.94. **Results from 2004:** Mean ± SD (μmol/L) Baseline/1month − intervention group: α -carotene 0.18 ± 0.20/0.19 ± 0.19; β -carotene 0.58 ± 0.48/0.64 ± 0.44; cryptoxanthin 0.62 ± 0.33/0.70 ± 0.31; lutein 0.39 ± 0.14/0.48 ± 0.18; lycopene 0.28 ± 0.11/0.26 ± 0.11	0.22 (0.01) [2];: α -carotene 0.37 (0.00); b-carotene 0.26 (0.00); b-cryptoxanthin 0.19 (0.02); Lutein 0.30 (0.00); total carotenoids; 0.32 (0.00); **Cooked vegetables** [1]**:** a-carotene; 0.14 (0.08); lutein 0.21 (0.01); total carotenoids 0.19 (0.02) [2];: α -carotene 0.24 (0.00); β -carotene 0.15 (0.05); b-cryptoxanthin 0.14 (0.07); lutein 0.24 (0.00); total carotenoids 0.23 (0.00); **Raw veg** [1]**:** α -carotene 0.20 (0.01); β carotene 0.17 (0.03); lutein 0.20 (0.01); total carotenoids 0.21 (0.01) [2];: α -carotene 0.31 (0.00); β carotene 0.25 (0.00); -cryptoxanthin 0.23 (0.00); lutein 0.22 (0.01); total carotenoids 0.31 (0.00); **fruit** [1]**:** α -carotene 0.17 (0.04); β -carotene 0.22 (0.01); cryptoxanthin 0.42 (0.00); lutein 0.15 (0.06); total carotenoids 0.34 (0.00) [2];: a-carotene 0.15 (0.07); β -carotene 0.18 (0.02); cryptoxanthin 0.43 (0.00); total carotenoids 0.30 (0.00); **fruit juice** [1] **or** [2] **-** nil significant. **Results from 2004 (p<0.01 unless otherwise specified): total veg:** α-carotene 0.37; β-carotene 0.17($p < 0.05$); Lutein 0.26; total carotenoids 0.24; **total fruits:** α-carotene 0.23; β-carotene 0.23; cryptoxanthin 0.42; total carotenoids 0.39; **citrus fruits:** β-cryptoxanthin 0.57; total carotenoids 0.27; **total fruits and veg:** α-carotene 0.36; β-carotene 0.23; β-cryptoxanthin 0.31; Lutein 0.23; total carotenoids 0.37.	
Bolton-Smith et al. (1991) [193]	Mean ± SD (μg/day):β-carotene smokers 2924 ± 1695; non-smokers 3526 ± 2248	Mean ± SD (μg/l/day): carotenes smokers 166 ± 103; Non-smokers 238 ± 143.	Correlations smokers 0.03; non-smokers 0.26. Only significant in non-smokers ($p < 0.01$).	Few carotenoids reported.
Bone et al. (2000) [77]	Range of concentrations of lutein + zeaxanthin ($\mu g/ml^{-1}$): 0.08 −0.35.	UC	Correlation value lutein + zeazanthin $r = 0.74$; $p < 0.001$.	Methods poorly reported, small sample size
Bowman et al. (2011) [78]	UC	UC	α-carotene 0.49; β-carotene 0.43; cryptoxanthin 0.41; lutein + zeaxanthin 0.48; $p < 0.01$ for all. Not significant for lycopene.	Small sample size.
Brantsaeter et al. (2007) [79]	Mean + SD (μg/day) β -carotene: **FFQ:** nonsupplement users 2660 ± 1880; supplement users 4140 ± 2230; **4-day FR:** nonsupplement users 2130 ± 1770; supplement users 4410 ± 3190	Mean ± SD (μmol/L):**Non-supplement users** β-carotene 0.42 ± 0.20; total carotenoids 1.69 ± 0.51; **supplement users FFQ** b-carotene 0.58 ± 0.27; total carotenoids 2.03 ± 0.34; **supplement users food record** β -carotene 0.58 ± 0.23; total carotenoids 2.16 ± 0.65	Correlation between plasma b-carotene and FFQ b-carotene 0.16 (NS); plasma b-carotene and food record b-carotene 0.32($p < 0.01$).	Non-fasting blood collection, females only.
Brunner et al. (2001) [80]	Mean ± SD (μg/day) carotenes: **FFQ:** F 3100 ± 1741; M 2713 ± 1530; **7-day diary:** F 2221 ± 1230; M 2181 ± 1197	NR	Correlation between dietary carotenes and plasma β-carotene **FFQ** F 0.20($p < 0.001$); M 0.22 ($p < 0.0001$); **7-day diary** F 0.16 ($p < 0.01$); M 0.23 ($p < 0.0001$); Correlation between dietary carotenes and plasma β-carotene/cholesterol **FFQ** F 0.21 ($p < 0.001$); M 0.28 ($p < 0.0001$); **7-day diary** F 0.20 ($p < 0.001$); M 0.29 ($p < 0.0001$).	Plasma carotenoid data UC/NR.

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Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
Burri et al. (2010) [81]	Mean ± SD lycopene (μg/day): **3-day diet record** 5054 ± 5875; **FFQ** 6656 ± 7671	Mean ± SD (μmol/L): 0.51 ± 0.26	Regression of association of dietary lycopene (**FFQ**) and serum lycopene, adjusted for bioaccessibility, energy and fat (parameter estimate 0.0089, P = 0.043, for energy; 0.0027, P = 0.0001, for bioaccessibility). Model of association of dietary lycopene **(3-FR**) and serum lycopene, (0.0072 for energy and 0.0098 for bioaccessibility, P = 0.0001 for both). 3D-DR, lycopene adjusted for bioaccessibility, and FFQ lycopene adjusted for bioaccessibility were significantly associated with serum lycopene concentrations (P = 0.001), whereas the relation between FFQ corrected for energy and serum lycopene approached significance (P = 0.053). Correlation between serum lycopene and dietary lycopene estimated by the FFQ (0.35). Method of triads: FFQ and 3D-DR estimates of lycopene adjusted for bioaccessibility were correlated with serum lycopene (0.33; 0.48 respectively).	Exclusion of smokers - not representative of wider population. Small sample size.
Campbell et al. (1994) [26]	Servings/day, Mean (SD) − F + V 52.9 (32.4) F 22.2 (15.8) V 30.7 (20.7) High lutein foods 5.5 (5.9); High lycopene foods 7.0 (4.2); High β-carotene foods 6.0 (6.5)	(μg/dl); α-carotene − 5.6 ± 4.3; β-carotene − 15.7 ± 11.7; cryptoxanthin - 8.3 ± 4.7; Lutein - 18.0 ± 6.2; Lycopene − 37.3 ± 14.7;	High β-carotene foods (r = 0.41); high lutein foods (r = 0.46); and high lycopene foods (r = 0.1 1)	Dietary carotenoids UC
Canfield et al. (1997) [83]	3-d FR (ug/day): α-carotene; 1303 ± 762; β - carotene 5078 ± 2473; lutein 2754 ± 2600; lycopene 4551 ± 3447	**Group 1, n = 6; μmol/L, mean ± SEM** α-carotene 0.25 ± 0.01; β-carotene 0.75 ± 0.2; β-cryptoxanthin 0.18 ± 0.04; lutein plus zeaxanthin 0.29 ± 0.01; lycopene 0.58 ± 0.03 & **(Group 2, n = 6; μmol/L, mean ± SEM)** α-carotene 0.23 ± 0.08; β-carotene 0.64 ± 0.2; β-cryptoxanthin 0.20 ± 0.01; lutein plus zeaxanthin 0.28 ± 0.01; lycopene 0.76 ± 0.01	Correlation between diet and serum levels not reported.	Females only and correlation between diet and blood levels UC.
Canfield et al. (2001) [84]	**No. of mothers reporting servings of fruits and vegetables: 0 serves: n** = 24 **1:** 30 **2:** 17 **3:** 14 **4:** 4 **5:** 4 > **6:** 1 **No. of mothers reporting servings of fruits and vegetables high in B-carotene: 0 serves: n** = **76 1:** 17 **2:** 1 **3:** 0 **4:** 0 **5:** 0 > **6:** 0	**(Placebo, n = 18; μmol/L, mean ± SEM)** α-carotene 0.076 ± 0.03; β-carotene 0.267 ± 0.12; cryptoxanthin 0.047 ± 0.03; lutein plus zeaxanthin 0.13 ± 0.03; lycopene 0.225 ± 0.08 & **(Palm Oil Carotene, n = 31; μmol/L, mean ± SEM)** α-carotene 0.086 ± 0.03; β-carotene 0.322 ± 0.39; β-cryptoxanthin 0.04 ± 0.01; lutein plus zeaxanthin 0.117 ± 0.04; lycopene 0.175 ± 0.08 & **(Carotene Supplement, n = 36; μmol/L, mean ± SEM)** α-carotene 0.067 ± 0.03; β-carotene 0.207 ± 0.01; β-cryptoxanthin 0.039 ± 0.02; lutein plus zeaxanthin 0.131 ± 0.04; lycopene 0.195 ± 0.08	Correlation between diet and serum levels not reported.	Females only and correlation between diet and blood levels UC.
Cappuccio et al. (2003) [85]	**Fruit intake (portions/day): Mean (SE)** F: 1.8 (0.1) M: 1.8 (0.1) **Vegetable:** F: 1.8	β-carotene (μmol/L) − 1.18 (0.6) for males and 1.01 (0.8) for females	Correlation between diet and plasma levels not reported.	Dietary carotenoids

	(0.1) M: 1.9 (0.1) **F&V:** F: 3.6 (0.1) M: 3.7 (0.2)			
Carlsen et al. (2011) [86]	**FFQ intakes (g/d) Median (IQ range)** Fruit and juice: 220 (147–368) Vegetables: 243 (166–332) Fruit, juice & veg: 513 (354–644) **WR intakes** Fruit and juice: 248 (117–363) Vegetables: 161 (118–222) Fruit, juice & veg: 418 (269–591)	nmol/L – Median (IQ Range): α-carotene 98 [57–168]; β-carotene 414 (274–616); β-cryptoxanthin 141 (83–211); lutein 156 (122–209); zeaxanthin 39 [28–53]; lycopene 567 (403–758); TOTAL 1529 (1156–2031)	Correlation between diet and plasma levels not reported.	Dietary carotenoids UC
Carroll et al. (1999) [87]	**Estimated records (μg/d) Mean (SD) YM = younger male/OM = older male/ YF = younger female/OF = older female.** **α-carotene:** YM 775 (656)/OM 812 (651)/YF 771 (598)/OF 973 (530) **β-carotene:** YM 2921 (1797)/OM 3099 (2060)/YF 2850 (1539)/OF 3358 (1447) **Cryptoxanthin:** YM 189 (288)/OM 116 [153]/YF 165 [157]/OF 108 [160] **Lutein + Zeaxanthin:** YM 1005 (675)/ OM 778 (320)/YF 943 (385)/OF 1015 (463) **Lycopene:** YM 3198 (4129)/OM 2092 (1809)/YF 2877 (2066)/OF 2285 (2367) **Total:** YM 8089 (5002)/OM 6899 (4624)/YF 7605 (3007)/OF 7739 (3245) **FFQ** **α-carotene:** YM 2285(1470)/OM 1217 (1375)/YF 2426 (1872)/OF 1223 (797) **β-carotene** YM 8077 (4463)/OM 5277 (4607)/YF 8795 (6022)/OF 5496 (3035) **cryptoxanthin:** YM 471 (466)/OM 295 (346)/YF 727 (803)/OF 317 (338) **Lutein + Zeaxanthin:** YM 2323 (1436)/ OM 1877 (1462)/YF 2615 (2120)/OF 2120 (1277) **Lycopene:** YM 7642 (6262)/OM 2026 (2211)/YF 8045 (9393)/OF 4615 (5368) **Total:** YM 20800 (9563)/OM 10693 (8475)/YF 22608 (16368)/OF 13773 (8823)	**Plasma (nmol/L) Mean (SD)** **α-carotene:** YM 92 [43]/OM 122 [81]/YF 107 [53]/ OF 166 [94] **β-carotene:** YM 393 [194]/OM 472 (222)/YF 462 [186]/OF 553 (254) **cryptoxanthin:**YM191 [113]/OM 117 [96]/YF 296 (226)/OF 123 [62] **Lutein:** YM 207 [70]/OM 140 [62]/YF 237 [73]/OF 170 [56]**Zeaxanthin:** YM 97 [40]/OM 49 [25]/YF 83 [25]/OF 57 [19] **Lutein + Zeaxanthin:** YM 304 [99]/OM 187 [73]/YF 320 [94]/ OF 223 [73]**Lycopene:** YM 297 [125]/OM 91 [69]/YF 253 [110]/OF 111 [61] **Total:** YM 1693 (473)/OM 992 (395)/ YF 1813 (567)/OF 1177 (436)	Plasma carotenoid concentrations may be a useful biomarker of several carotenoids, excluding b-carotene, in groups aged 24 ± 45 y.	
Cartmel et al. (2005) [88]	Reported F & V serves	**Placebo; nmol/L, median (25–75th percentile range)** α-carotene 52 [28–98]; β-carotene 208 (123–336); β-cryptoxanthin 55 [43–158]; lutein 164 (107–222); zeaxanthin 47 [31–62]; lycopene 302 (158–447) & **Intervention** α-carotene 46 [30–90]; β-carotene 249 (113–482); β-cryptoxanthin 79 [54–145]; lutein 161 (128–215); zeaxanthin 49 [37–70]; lycopene 304 (191–477)	Plasma carotenoid conc increased with increase in fruit & vegetable intervention	Dietary carotenoids UC
Cena et al. (2008) [89]	Lutein and Zeaxanthin; 1107 ± 113 μg/day by FFQ and 1083 ± 116 μg/day by 7-d food record analysis	Lutein and Zeaxanthin; 0.33 ± 0.09 μmol/L	Dietary intake of lutein and zeaxanthin measured with the FFQ and plasma concentration were significantly correlated ($r = 0.76$, $P < 0.0001$).	Major carotenoids not determined
Cena et al. (2009) [90]	Mean (SD) – Dietary Lutein 1242 [113] μg/d	Mean (SD) – Plasma Lutein 0.69 (0.49) μmol/L	Both breast milk and plasma lutein concentrations were significantly correlated with dietary lutein intake ($r = 0.86$, $P = 0001$ and $r = 0.94$, $P = 0001$, respectively).	Major carotenoids not determined

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Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
Chung et al. (2009) [91]	μ/day − (Mean ± SEM): α-carotene (367.2 ± 48.3); β-carotene (2960.7 ± 393.9); β-cryptoxanthin (135.5 ± 22.3); lutein plus zeaxanthin (2534.6 ± 439.3); lycopene 2105.4 ± 341.2)	nmol/L − (Mean ± SEM): α-carotene (98.6 ± 18.2); β-carotene (568.8 ± 71.7); β-cryptoxanthin (422.4 ± 68.6); lutein plus zeaxanthin (231.9 ± 23.9); lycopene (405.8 ± 32.4)	Dietary intake was significantly correlated with serum concentrations of α-carotene, β-carotene, and cryptoxanthin.	
Ciulla et al. (2001) [92]	μg/day − (Mean ± SD): β-carotene (2772 ± 2134); lutein plus zeaxanthin (1102 ± 839)	μmol/L − (Mean ± SD): β-carotene (0.281 ± 0.287); lutein plus zeaxanthin (0.372 ± 0.169)	Statistically significant ($P < 0.05$) relationships were found between macular pigment density and serum lutein plus zeaxanthin & dietary lutein plus zeaxanthin	Other carotenoids not determined
Coates et al. (1991) [194]	μg/day − (Mean ± SEM): α-carotene (185.2 ± 19.6); β-carotene (2657 ± 224); β-cryptoxanthin (174 ± 16.7); Lutein (3407 ± 357); Lycopene (257 ± 32.0)	μg/dL − (Mean ± SEM): α-carotene (3.40 ± 0.44); β-carotene (20.4 ± 1.74); β-cryptoxanthin (8.43 ± 0.56); lutein plus zeaxanthin (24.2 ± 1.8); lycopene (21.5 ± 1.25)	Little correlation between dietary and serum carotenoid levels.	
Cooney et al. (1995) [94]	Not reported	μmol/L − (Mean ± SD): α-carotene (0.17 ± 0.11); β-carotene (0.64 ± 0.64); β-cryptoxanthin (0.29 ± 0.18); lutein plus zeaxanthin (0.41 ± 0.14); lycopene (0.52 ± 0.22)	Diet history showed good agreement with plasma levels for most carotenoids.	Dietary carotenoids UC
Curran-Celentano et al. (2001) [95]	μg/day − (Mean ± SD): β-carotene (2935 ± 2698); Lutein + zeaxanthin (1101 ± 838); Lycopene (8366 ± 6106)	μmol/L − (Mean ± SD): β-carotene (0.28 ± 0.29); Lutein (0.28 ± 0.13); Zeaxanthin (0.091 ± 0.044); Lycopene (0.601 ± 0.288)	Serum lutein + zeaxanthin and dietary intake of lutein + zeaxanthin were significantly correlated	
Dauchet et al. (2008) [96]	**Mean (SD)** **Vegetables + Fruits + Juices M:** 416 [182]F: 465 [156] **Vegetables** M: 198 [87] F: 213 [80] **Fruits + Fruit Juices** M: 218 144) F: 242 [118] **Fruits** M: 180 [128] F: 199 [104]**Fruit Juices** M: 37 [66] F: 43 [57]	μmol/L − Median (Range): β-carotene 0.33 (0.18−0.54)	Root vegetables and citrus fruits were particularly associated with serum b-carotene	Dietary carotenoids UC
Daures et al. (2000) [97]	β-carotene (mean ± SD) = 4.2 ± 8.4 mg/day	blood levels not reported	For β-carotene intake assessment, the triad model was the best with estimates of validity coefficient of 0.39 (CI 0.18−0.60) for the FFQ and 0.85 (CI 0.43−1.0) for plasma level.	Other carotenoids not reported
Dixon et al. (1996) [98]	Dietary total carotenoids (Mean ± SD): FFQ - 3167 ± 1815 and 3 d FR − 3563 ± 2545	Mean (SD): α-carotene 0.12 (0.08) μmol/L; β-carotene 0.41 (0.28); β-cryptoxanthin 0.28 (0.43); lutein plus zeaxanthin 211 [75] **ug/L**ycopene 0.29 (0.11) μmol/L; TOTAL 835 (343) **ug/L**	Total Carotenoids ($P < 0.005$)	Serum total and lutein plus zeaxanthin units as ug/L while all other carotenoids as umol/L.
Dixon et al. (2006) [99]	μg/d Mean (95% CI) **DHQ α-carotene** W: 526 (429, 646) M: 425 (308, 587) **β-carotene** W: 2683 (2277, 3160) M: 2452 (1916, 3138) **β-cryptoxanthin** W: 130 [109,154] M: 129 [103,163] **lutein plus zeaxanthin** W: 2119 (1827, 2459)M: 2068 (1682, 2543) **lycopene** W: 5612 (4815, 6540) M: 6762 (5486, 8335) **4 × 24-HR α-carotene** W: 332 (237,	μmol/L − Mean (95%CI): **F** α-carotene 0.11 (0.09−0.13); β-carotene 0.31 (0.25−0.38); β-cryptoxanthin 0.09 (0.08−0.11); Lutein plus zeaxanthin 0.28 (0.25−0.31); Lycopene 0.61 (0.54−0.69) **M** α-carotene 0.07 (0.05−0.09); β-carotene 0.21 (0.16−0.27); β-cryptoxanthin 0.08 (0.07−0.10);	Using the method of triads, validity coefficients for the DHQ were comparable to the 4 × 24-HR and were especially strong for a-carotene, cryptoxanthin, lutein + zeaxanthin	Dietary carotenoids not listed

	465) M: 209 (128, 339) **β-carotene** W: 1956 (1609, 2377) M: 2049 (1565, 2684) **cryptoxanthin** W: 58 (44, 76) M: 95 [63,142] **lutein plus zeaxanthin** W: 1410 (1214, 1638) M: 1616 (1340, 1949) **lycopene** W: 3505 (2495, 4922) M: 7658 (5860, 10,007)	lutein plus zeaxanthin 0.26 (0.23−0.30); lycopene 0.66 (0.58−0.74)		
Eliassen et al. (2006) [100]	Fruits and vegetable consumption Serves/day (Mean SD) − **Health Centre Participants** Usual Care - 3.0 (1.3) Intervention - 3.8 (1.7) **Small Business Participants** Usual Care − 3.2 (1.7) Intervention - 3.8 (1.9) **Together** Usual Care - 3.1 (1.6) and Intervention - 3.8 (1.8)	USUAL CARE μg/L − Mean (SD): α-carotene 47 (27.7); β-carotene 194.4 (107.1); β-cryptoxanthin 80.3 (38.6); lutein plus zeaxanthin 201 (67.8); lycopene 463.5 (162.2) AND INTERVENTION: α-carotene 64 (48.7); β-carotene 241 (143.9); β-cryptoxanthin 80 (37.2); lutein plus zeaxanthin 194.7 (64.5); lycopene 489.3 (138.8)	F&V intake was significantly correlated with α-carotene when both groups were combined, (P = 0.02), β-carotene (P = 0.006) in the usual care group but not in the intervention group. In the usual care group, the correlations of lutein plus zeaxanthin (P = 0.03) and β-cryptoxanthin P = 0.01) with fruit and vegetable intake were higher than in the intervention group (P = 0.08, 0.09).	Dietary carotenoids UC
El-Sohemy et al. (2002) [101]	**M μg/d - Mean (SD):** α-carotene 447 (449); β-carotene 3407 (2407); β-cryptoxanthin 383 (446); lutein plus zeaxanthin 2412 (2857); lycopene 5451 (5274) **F:** α-carotene 727 (849); β-carotene 4668 (3564); β-cryptoxanthin 552 (523); lutein plus zeaxanthin 2893 (2487); lycopene 5772 (4789)	**M nmol/L - Mean (SD):** α-carotene 135 [92]; β-carotene 484 (407); β-cryptoxanthin 181 (202); lutein plus zeaxanthin 316 [143]; lycopene 501 (338) **F:** α-carotene 180 [151]; β-carotene 821 (725); cryptoxanthin 275 (295); lutein plus zeaxanthin 328 [165]; lycopene 585 (338)	α-carotene; β-carotene; lutein plus zeaxanthin; cryptoxanthin; lycopene	
Enger et al. (1995) [102]	μg/d − Mean (SD): **Modified FFQ:** α-carotene 940 (790); β-carotene 4800 (3230); β-cryptoxanthin 70.1 (66.3); lutein plus zeaxanthin 3230 (2290); lycopene 5180 (3860) **Willet FFQ:** α-carotene 940 (790); β-carotene 4770.0 (3220.0); β-cryptoxanthin 69.5 (68.2); lutein plus zeaxanthin 3270.0 (2500.0); lycopene 4280 (3520.0)	μmol/L − Mean (SD): α-carotene 0.138 (0.123); β-carotene 0.571 (0.423); β-cryptoxanthin 0.367 (0.231); lutein plus zeaxanthin 0.324 (0.136); lycopene 0.742 (0.380)	The crude and partial correlation coefficients of dietary and plasma levels of b-carotene are slightly lower than those found in other studies	
Faure et al. (2006) [103]	**M: β-Carotene (mg/day)** Means± 3140 ± 1540 (35−45yrs); 4090 ± 2290 (45−50yrs); 4110 ± 2310 (50−60yrs); 4470 ± 2240 (60−63yrs) **F:** 3790 ± 2152 (35−45yrs); 3810 ± 2164 (45−50yrs); 4120 ± 2216 (50−60yrs); 4100 ± 1931 (60−63yrs)	Not reported	In male volunteers, serum b-carotene was significantly related to tobacco smoking, alcohol consumption estimated dietary intake, serum cholesterol, and serum triglycerides while in female volunteers it was dependant on tobacco smoking, cholesterol, serum triglycerides, and serum cholesterol. Estimated dietary intake of b-carotene was higher in the 50- to 63-year-old volunteers, it was significantly higher in nonsmokers, and higher in the summer.	Other carotenoids not reported
Fawzi et al. (2004) [104]	**μg/d (mean ± SD): AFRICAN AMERICANS** α-carotene 586 ± 740, lutein plus zeaxanthin 3207 ± 2915, lycopene 5017 ± 4557: **CAUCASIANS** α-carotene 656 ± 577, lutein plus zeaxanthin 2928 ± 2089, lycopene 8717 ± 6511	**μg/L (mean ± SD): AFRICAN AMERICANS** α-carotene 64 ± 32, lutein plus zeaxanthin 212 ± 38.7, lycopene 446 ± 57: **CAUCASIANS** α-carotene 81 ± 22, utein plus zeaxanthin 219 ± 46, lycopene 444 ± 79	Plasma α-carotene levels were: 1.9 (p = 0.10) and 2.9 (p = 0.0007) mg/L higher for every 100 mg increase in dietary intake amongst African American and Caucasian respectively. Extreme dietary deciles saw an increase in a-carotene of 275% for African Americans and 152% for Caucasian women Increases were also seen for lycopene, lutein, and g-tocopherol, ranging from 12% to 64%.	Other carotenoids not reported

(*continued on next page*)

Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
Ferrari et al. (2005) [105]	**Region Specific means (SE) of carrot, fruit and tomato intake (all g/day) for DQ and 24-HDR** **France**Carrot: 20.0 (1.7) and 11.2 (2.9) Fruit: 249.9 (13.6) and 232.5 (17.6) Tomato: 22.0 (1.8) and 44.7 (8.6) **Florence, Italy** Carrot: 12.4 (1.2) and 4.6 (1.2) Fruit: 336.0 (12.6) and 349.7 (22.8) Tomato: 85.4 (3.9) and 79.6 (7.2) **Vares/ Turin Italy** Carrot: 16.4 (1.4) and 7.2 (2.0)Fruit: 354.0 (14.6) and 379.7 (19.0) Tomato: 83.9 (3.6) and 77.2 (8.1) **Ragusa/Naples Italy** Carrot: 9.7 (1.4) and 2.9 (1.0)Fruit: 514.5 (23.0) and 382.7 (21.4)Tomato: 48.9 (2.4) and 77.1 (8.3) **Northern Spain** Carrot: 9.0 (1.8) and 5.8 (1.1) Fruit: 344.9 (17.4) and 337.8 (18.3) Tomato: 69.2 (4.8) and 49.6 (5.9) **Granada Spain** Carrot: 7.9 (0.9) and 7.7 (1.1) Fruit: 339.4 (14.8) and 359.7 (19.2) Tomato: 100.7 (5.0) and 99.2 (8.6) **Murcia Spain** Carrot: 5.7 (0.7) and 6.5 (1.3) Fruit: 409.2 (15.2) and 408.6 (21.3) Tomato: 94.5 (4.7) and 105.2 (7.2) **Cambridge UK** Carrot: 28.8 (1.4) and 21.2 (2.4) Fruit: 218.9 (10.6) and 163.8 (13.3) Tomato: 42.4 (2.0) and 42.5 (4.1) **Oxford UK** Carrot: 39.4 (2.5) and 21.8 (3.9) Fruit:425.7 (32.5) and 298.8 (19.5) Tomato: 54.1 (3.2) and 81.1 (7.2) **The Netherlands** Carrot: 13.0 (0.8) and 8.8 (2.6) Fruit: 218.2 (9.5) and 204.6 14.2) Tomato: 15.7 (0.9) and 22.3 (4.8) **Athens, Greece** Carrot: 32.9 (3.1) and 8.7 (0.2) Fruit: 654.7 (30.5) and 259.1 (17.3) Tomato: 163.6(6.4) and 101.2 (8.9) **Heidelberg Germany** Carrot: 8.2 (0.6) and 11.2 (2.5) Fruit: 148.4 (7.2) and 157.3 (14.2) Tomato: 34.5 (1.5) and 47.4 (6.4) **Potsdam Germany** Carrot: 8.0 (0.7) and 11.4 (3.7) Fruit: 163.4 (7.0) and 261.8 (16.7) Tomato: 26.2 (1.4) and 52.2 (6.2) **Malmo Sweden** Carrot: 22.4 (2.3) and 13.4 (2.4)Fruit: 186.5 (8.8) and 131.0 (10.1) Tomato: 45.8 (2.6) and 47.1 (4.7) **Umea Sweden** Carrot: 37.8 (3.8) and 16.6 (2.8) Fruit: 161.8 (9.3) and 153.0 (11.0)Tomato: 18.4 (1.5) and 39.9 (3.8) **Denmark** Carrot: 34.3 (3.4) and 21.7 (3.9) Fruit: 193.8 (11.8) and 196.5 (16.0) Tomato: 42.9 (1.9) and 38.6 (5.0)	**Region specific means (SE) of α-carotene/B-cryptoxanthin/Lycopene (all μmol) France** 0.32 (0.02)/0.29 (0.02)/0.69 (0.04) **Florence, Italy** 0.14 (0.01)/0.30 (0.02)/0.96 (0.03) **Vares/Turin Italy** 0.19 (0.01)/0.40 (0.02)/0.97 (0.03) **Ragusa/Naples Italy** 0.13 (0.01)/0.43 (0.02)/1.31 (0.03) **Northern Spain** 0.09 (0.01)/0.39 (0.02)/0.48 (0.02) **Granada Spain** 0.09 (0.01)/0.44 (0.02)/0.70 (0.03) **Murcia Spain** 0.08 (0.01)/0.44 (0.02)/0.70 (0.02) **Cambridge UK** 0.21 (0.01)/0.17 (0.01)/0.75 (0.02) **Oxford UK** 0.29 (0.02)/0.22 (0.01)/0.93 (0.03) **The Netherlands** 0.10 (0.01)/0.22 (0.01)/0.50 (0.02) **Athens, Greece** 0.11 (0.01)/0.40 (0.02)/0.86 (0.03) **Heidelberg Germany** 0.20 (0.01)/0.20 (0.01)/0.58 (0.02) **Potsdam Germany** 0.17 (0.01)/0.22 (0.01)/0.64 (0.02) **Malmo Sweden** 0.15 (0.01)/0.16 (0.01)/0.49 (0.02) **Umea Sweden** 0.22 (0.01)/0.19 (0.01)/0.50 (0.02) **Denmark** 0.19 (0.01)/0.17 (0.01)/0.56 (0.02)	Intraclass correlation coefficients were 0.178 for a-carotene, 0.216 for cryptoxanthin and 0.299 for lycopene	Values for plasma carotenoids not presented

Floreani et al. (2000) [106]	**Fruits (g/day, mean ± SD)** − 193 ± 132 for cholestasis patients & 201 ± 14 for controls; **Vegetables** − 171 ± 97 for cholestasis patients & 166 ± 10 for controls **Total carotenoids** − 5.73 ± 5.5 for cholestasis & 5.1 ± 1.9 for controls	**Primary biliary cirrhosis (μmol/L);** α-carotene − 0.14 ± 0.10; β-carotene − 0.738 ± 0.47; cryptoxanthin − 0.384 ± 0.31; Lutein − 0.444 ± 0.24; zeaxanthin − 0.128 ± 0.08 Lycopene - 0.480 ± 0.32; **Primary sclerosing cholangitis** α-carotene − 0.18 ± 0.13; β-carotene − 0.574 ± 0.28; cryptoxanthin − 0.401 ± 0.24; Lutein − 0.420 ± 0.19; zeaxanthin − 0.119 ± 0.06 Lycopene − 0.519 ± 0.23; **AND CONTROLS** α-carotene − 0.26 ± 0.22; β-carotene − 1.449 ± 0.98; cryptoxanthin − 0.31 ± 0.25; Lutein − 0.744 ± 0.43; zeaxanthin − 0.297 ± 0.18 Lycopene − 0.803 ± 0.44;	No validation examined	Cholestasis patients have malabsorption of fat soluble nutrients
Forman et al. (1993) [46]	**FFQ (μg/day)** α -carotene 840 ± 621, β - carotene 3882 ± 2452, cryptoxanthin 62 ± 59, lutein plus zeaxanthin 2516 ± 1528, lycopene3879 ± 3025 Total 11179 ± 7685 **Food diary** α -carotene 650 ± 567, β - carotene 3150 ± 2156, β - cryptoxanthin 38 ± 63, lutein plus zeaxanthin 2056 ± 2311, lycopene 3652 ± 3123 Total 9546 ± 6034	(mmol/L) α -carotene 0.09 ± 0.07, β − carotene 0.58 ± 0.3,cryptoxanthin 0.24 ± 0.16, lutein plus zeaxanthin 0.49 ± 0.19, lycopene 1.06 ± 0.41 Total 2.46 ± 0.65	β − carotene 0.36, cryptoxanthin 0.33	Males only
Freedman et al. (2010) [107]	lutein plus zeaxanthin (μg/day, mean and SD) − 1848 (1284) for controls and 1788 (1226) for cases	lutein plus zeaxanthin (μmol/L, mean and SD) −0.33 (0.16) for controls and 0.30 (0.14) for cases	Association of nuclear cataract risk with combined- reported dietary lutein/ zeaxanthin and serum lutein/zeaxanthin.	Other carotenoids not reported
Freisling et al. (2009) [108]	α-carotene (mg) Geometric mean (95% CI) **Poor (n=81)** 1.8 (1.4−2.2) **Fair (n = 67)** 1.6 (1.3−2.0) **Good (n = 86)** 2.1 (1.7 −2.5) **Very Good (n = 62)** 2.5 (2.0−3.2)	**Means (95%CI) by FFI categories (μg/L). Poor** α-carotene − 50 [32−67] β-carotene - 181 (135−226) cryptoxanthin − 52 [41−63] Lutein − 175 (150 −200)Zeaxanthin − 28 [24−32] **Fair** α-carotene − 38 [28−47] β-carotene - 224 (169−278) cryptoxanthin − 58 [46−69] Lutein − 180 (154 −205) Zeaxanthin − 26 [22−30] **Good** α-carotene − 40 [28−53] β-carotene - 221 (169−273) cryptoxanthin − 68 [56−80] Lutein − 191 (168 −214)Zeaxanthin − 32 [25−38]**Very Good** α-carotene − 45 [34−56]β-carotene - 292 (237−348) cryptoxanthin − 78 [66−90] Lutein − 204 (180 −228) Zeaxanthin − 32 [28−37]	FFI scores were positively correlated with plasma concentrations of β-carotene (r = 0.26), cryptoxanthin (r = 0.31), lutein (r = 0.21) zeaxanthin (r = 0.19),	Lycopene not reported and plasma values not reported as such
Galan et al. (2005) [109]	β - carotene (mean ± sd): M 4.1 ± 2.5 F 4.0 ± 2.6(mg/day)	(μmol/L) M = 0.47 ± 0.35; F = 0.67 ± 0.43	β-carotene r = 0.21, P < 0.001)	
George et al. (2012) [38]	Fruit & vegetable (no potato), intakes reported; no. of serves, mean(SD) **F F&V** = DHQ = 6.6(3.6); recalls = 5.1(2.7); F&V screener = 2.1(1.3) |**M F&V:** HQ = 6.8(4.1); Recalls = 5.9(3.0); F&V screener = 4.6(1.7). **F Fruit** = DHQ = 2.9(2.2); Recalls = 2.2(1.7); F&V screener = 2.1(1.3)|**Male Fruit intake:** DHQ = 2.8(2.4); Recalls = 2.5(2.0); F&V screener = 2.2(1.5). **Female Vegetable intake** = DHQ = 3.8(2.1); Recalls = 2.9(19); F&V	**F and M; (mean) μg/dl):** α-carotene - 7.0 and 5.5, trans-β-carotene - 24.7; 18.3, cryptoxanthin −11.0; 9.7, lutein - 12.5; 10.9, zeaxanthin - 3.1; 2.9, and cis-lycopene −20.3; 22.0 - and trans-lycopene - 20.6; 21.9	Unadjusted reported (F and M for FFQ|24R|screener): a-carotene: 0.44 and 0.39|0.36 nd 0.29|0.33 and 0.36;	

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Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
	screener = 2.1(0.7) **Male Vegetable intake:** DHQ = 4.0(2.7); Recalls = 3.4(1.9); F&V screener = 2.4(0.6).			
Gerber et al., 92000) [195]	Not reported - F &V classified by DQI score, median (g): Scores 1 to 4 (n = 10) = 760.2; 5 to 6 (n = 26) = 649.0; 7 (n = 21) = 577.8; Score 8 (n = 32) = 495.2; Score 9 (n = 20) = 451.3; Scores 11−14 (n = 18) = 283.1.	Reported by DQI score (μmol/L): Scores 1 to 4 = 1.04; Scores 5 to 6 = 1.01; Score 7 = 1.00; Score 8 = 1.06; Score 9 = 0.72; Score 10 = 0.80; Scores 11 to 14 = 0.170.	Plasma carotene: DQI (non-smokers) r = −0.12 (p = 0.157); DQI (smokers) = −0.17 (p = 0.045).	
Gomez-Aracena et al. (2003) [111]	μg/day(mean ± s.d.): α-carotene = 383 ± 297; β-carotene = 1595 ± 860; lycopene = 1359 ± 816	μg/100 mL: β-carotene = 30.9 ± 26.4; lycopene = 14.1 ± 6.9	α-carotene = 0.25; β-carotene = 0.27; lycopene = 0.25(all p < 0.01)	FFQ - 28 items for carotenes + addition of 2 for lycopene
Goodman et al. (1996) [112]	All β-carotene (n-1182) mg/d (mean; 95%CI): 2.0 (1.9−2.1)	ng/mL (mean; 95%CI): 143 [136−150]	β-carotene (diet vs serum) = 0.24(p < 0.05)	
Greene et al. (2008) [113]	Not reported - F &V only. 24R − Mean (95%CI)URI:M = 5.26(4.58 −6.00); F = 5.29(4.91−5.69); iT/ Rush:M = 5.09(4.38−5.85); Emory:M = 4.04(3.30−4.85); F = 3.99(3.65−4.35) FVS - Mean(95%CI): M = 8.32(7.12−9.61); F = 8.09(7.40 −8.82)|IIT/Rush: M = 5.24(4.35−0.22)| Emory: M = 5.00(3.52−6.74); F = 4.66(4.03−5.33)	Not reported	URI:M = n/s; F = 0.43 (p < 0.0001)| IIT/ Rush: M = n/s| Emory: F = n/s;	UC report carotenoids values for plasma carotenoids Final sample for serum carotenids differ to those for intake results, small sample of males
Grievink et al. (1999) [114]	Median (range):2.0(0.5−6.1)	0.30(0.00−2.07)	0.31 (sig not reported)	
Hallfrisch et al. (1994) [115]	**Quintile(IU): F:** 1 = 1306; 2 = 2608; 3 = 4411; 4 = 6698; 5 = 13910 **M:**1 = 1273; 2 = 2771; 3 = 4089; 4 = 6122; 5 = 11709	**Quintile; μmol/L(mean ± SEM): F:** 1 = 0.53 ± 0.10; 2 = 0.66 ± 0.10; 3 = 0.68 ± 0.10; 4 = 1.07 ± 0.10; 5 = 1.21 ± 0.10 **M:** 1 = 0.45 ± 0.06; 2 = 0.48 ± 0.06; 3 = 0.58 ± 0.06; 4 = 0.56 ± 0.06; 5 = 0.83 ± 0.06	(Age = <45; 45−59; 60−74; 75+) with carotene intake p < 0.0001	
Hammond et al. (1995) [116]	Not reported for group, instead reported for 1) twins with significantly different macular pigment and 2) twins with similar macular density	UC	Dietary lutein and zeaxanthin vs serum lutein, r = 0.48; vs serum zeaxanthin, r = 0.57. b-carotene, r = 0.67. Lycopene, r = 0.47. all p < 0.05.	
Hann et al. (2001) [117]	β-carotene (ug/d) presented by HEI score category: <65 (n = 58) = 217 ± 42; 65−74(n = 65) = 548 ± 149; 75 −84 = 871 ± 346; ≥85 = 806 ± 81	HEI score (μmol/L). **α-carotene(n = 332): <65** = 0.08; **65−74** = 0.14; **75−84** = 0.17; **≥85** = 0.22 **β-carotene: <65** = 0.49; **65−74** = 0.52; **75−84** = 0.68; **≥85** = 0.85 **cryptoxanthin: <65** = 0.11; **65−74** = 0.19; 75−84 = 0.23; ≥85 = 0.25 **lutein: <65** = 0.36; **65−74** = 0.36; **75 −84** = 0.48; **≥85** = 0.52 **lycopene: <65** = 0.71; **75 −84** = 0.73; **75−84** = 0.73; **≥85** = 0.74	α-carotene = 0.41; β-carotene = 0.30; cryptoxanthin = 0.40; lutein = 0.24 (all p < 0.05)	
Hebert et al. (1994) [118]	β-carotene, mean(SD) = 2126.2(1276.5) μg/day; total β-carotene (including supps) = 2186.2(1331.3)	0.35(0.27) μmol/L	0.32; p < 0.0001	
Hercberg et al. (1994) [119]	β-carotene (μg/d); median (5th, 95th percentiles): Categorised by age: 18-30yrs: M = 1057 (108, 2905); F = 1134 (228, 3091); 30−40yrs: M = 1228 (195, 3910); F = 1222 (306, 2978); 40−50yrs: M = 1434 (294, 3293); F = 1163 (174, 3170); 50−65yrs: M = 1433 (322, 3341); F = 1513 (238,	βcarotene (μg/d); median (5th, 95th percentiles): Categorised by age: 18−30yrs: M = 0.48(0.24, 1.38); F = 0.72(0.26, 1.80)); 30−40yrs: M = 0.65 (0.16, 1.92); F = 0.62 (0.26, 2.36); 40−50yrs: M = 0.48 (0.14, 1.83); F = 0.86 (0.29, 1.93); 50−65yrs: M = 0.63 (0.24, 1.61); F = 0.89 (0.36, 2.23); >65: M = 0.90 (0.10, 1.29); F = 0.90 (0.27, 2.23)	>18 yrs: M = 0.002(p < 0.005); F = 0.001 (p < 0.005)	

	2921); >65: M = 1562 (363, 3710); F = 1359 (592, 3974)			
Hendrickson et al. (2013) [19]	Mean ± SD μg/day Training/testing **α carotene** 776 ± 496/799 ± 509 **β carotene** 4397 ± 2193/4442 ± 2208 **Cryptoxanthin** 183 ± 92/184 ± 94 **Lutein/zeaxanthin** 2955 ± 1635/ 2950 ± 1630 **Lycopene** 6336 ± 3219 **Total carotenoids** 14696 ± 5452/ 14,697 ± 5560	Mean ± SD mg/dl **α carotene** 74 ± 50/74 ± 52 **β carotene** 291 ± 207/289 ± 212 **Cryptoxanthin** 84 ± 46/83 ± 43 **Lutein/zeaxanthin** 187 ± 74/ 181 ± 68 **Lycopene** 425 ± 176/419 ± 177 **Total carotenoids** 1080 ± 403/1062 ± 394	Training/Testing **α carotene** 0.34/0.31 (P < 0.001) **β carotene** 0.26/0.29 (P < 0.001) **Cryptoxanthin** 0.34/ 0.36 (P < 0.001) **Lutein/zeaxanthin** 0.26/ 0.28 (P < 0.001) **Lycopene** 0.22/0.22 **Total carotenoids** 0.20/0.22 (P < 0.001)	
Hiroaka et al. (2001) [120]	Sum of carotene and retinol only presented as Vitamin A (μgRE); mean (SD): 727(861)	β-carotene (μmol/L): 1.33(1.20)	r = 0.319; p < 0.001)	
Hodge et al. (2009) [121]	Unadjusted: Median (IQR): α-carotene: M = 1245(558−1618); F = 1130 (654−1799)|β-carotene: M = 5142 (3315−7028); F = 5266 (3866 −7125) | cryptoxanthin: M = 324 (160 −588); F = 349 (180−592) | Lutein/ zeaxanthin: M = 1615 (1064−2282); F = 1697 (1193−2304) Lycopene: M = 7108 (4067−10513); F = 6264 (3995−9446)|	Unadjusted: Median (IQR): α-carotene: M = 0.08 (0.04−0.13); F = 0.11 (0.07 −0.17)| β-carotene: M = 0.48 (0.28−0.77); F = 0.78 1 (0.47 −1.06)| cryptoxanthin: M = 0.16 (0.09−0.31); F = 0.27 (0.15 −0.45)| Lutein/zeaxanthin: M = 0.30 (0.21−0.43); F = 0.33 (0.23−0.43) Lycopene: M = 0.50 ((0.32−0.75); F = 0.51 (0.35 −0.72)|	r (% 95 CI): **α-carotene** (n = 2744) = 0.35 (0.31, 0.38)| **β-carotene** (n = 2876) = 0.23 (0.19, 0.26)| **cryptoxanthin** (n = 2975) = 0.40 (0.36, 0.43)|**Lycopene** (n = 2679) = 0.21 (0.18, 0.25)|**lutein/zeaxanthin** (n = 2990) = 0.21 (0.18, 0.25)	
Holmes et al. (2007) [32]	β-carotene (μg/d); mean(SD): 4330(3712) lycopene: 6239(4447). **median per decile (n = 10, with decile#3 + 4, 5 + 6, 7 + 8 combined):** b-carotene: **1** = 1256; **2** = 1773; **3** + **4** = 2321; **5** + **6** = 3084; **7** + **8** = 4239; **9** = 7204; **10** = 11,777 lycopene: **1** = 1145; **2** = 2237; **3** + **4** = 3410; **5** + **6** = 5546; **7** + **8**=8074; **9** = 10,225; **10**=16,054.	Median per decile (n = 10, with decile#3 + 4, 5 + 6, 7 + 8 combined):β **-carotene** 1 = 129; 2 = 129; 3 + 4 = 231; 5 + 6 = 316; 7 + 8 = 294; 9 = 290; 10 = 500 **Lycopene:** 1 = 418; 2 = 411; 3 + 4 = 365; 5 + 6 = 404; 7 + 8 = 369; 9 = 449; 10 = 551.	Generalised estimating equations: % increase in blood levels from decile 1 to 10: β-carotene = 288% lycopene = 32%;	
Iribarren et al. (1997) [122]	Quartiles by serum b-carotene (energy-adjusted residual method). pro-Vitamin A carotenoids (IU/day): 1 = 6067; 2 = 5905; 3 = 6878; 4 = 8258	Absolute range (μmol/L: 1 = 0.03−0.20; 2 = 0.21−0.31; 3 = 0.32−0.46; 4 = 0.47−1.62	r = 0.11; p-0.04	Single assessment of serum carotenoids
Jacques et al. (1995) [123]	Total carotenoids, median (IQR), mg/ d (n = 746): M = 3.1 (5.6); F = 3.5 (5.9)	Reported (mean, 95%CI) per intake category and combined (μmol/L): <2 mg = 2.2 (2.1, 2.3); 2.0 −5.4 mg = 2.5 (2.3,2.6); ≥5.5 mg = 2.8 (2.6, 2.9)	Plasma cartoenoids 27% (0.6 μmol/L) greater in the highest compared to lowest category (p for trend <0.001)	
Jansen et al. (2004) [124]	Mean (SD) intake − **Vegetables (g/d):** M = 113(49); F = 127(50) **Fruit)g/d):** M = 153(125); F = 186(145) **fruit juices (g/d):** M = 79(92; F = 86(89)**veg juices (g/ d):**M = 5(8); F = 7(12)	Mean (SD); μmol/L − **α-carotene**: M = 0.081(0.060); F = 0.120(0.090) **β-carotene:** M = 0.240(0.152); F = 0.302(0.184) **cryptoxanthin:** M = 0.167 (0.132); F = 0.225 (0.167) **lutein:** M = 0.251 (0.098); F = 0.304(0.111) **zeaxanthin:** M = 0.066 (0.028); F = 0.085 (0.034) **lycopene:** M = 0.62 (0.308); F = 0.658 (0.341) **canthaxanthin:** M = 0.010 (0.013); F = 0.009 (0.015)**total:** M = 1.435 (0.514); F = 1.704 (0.606)	All = r and p < 0.05. **α-carotene vs Fr + V + J**: M = 0.29; F = 0.0.28| **vs V:** M = 0.21; F = 0.17 | **vs Fr:** M = 0.28; F = 0.28|**J** = M = 0.12. **β-carotene vsFr + V + J:** M = 0.24; F = 0.17 |**V:** M = 0.19; F = 0.15 | **Fr:** M = 0.25; F = 0.18 |**J:** N/S. **b-cryptoxanthin vs V + Fr + J:** M = 0.41; F = 0.35|**v:** M = 0.13; F=N/S. **Fr:** M = 0.37; F = 0.37|**J:** m = 0.29; F = 0.21. **Lutein vs V + Fr + J:** M = 0.19; F = 0.20 |**V:** M = 0.27; F = 0.19|**Fr:** M = 0.16; F = 0.18 |**J:** N/S. **Zeaxanthin vs. V + Fr + J:** m = 0.18; M = 0.23 |**V:** m = 0.16; F=N/S |**J**=M = 0.21; F = 0.23. **Lycopene** = n/s. **Total vs V + Fr + J:** M = 0.21; F = 0.18 |**V:** M = 0.19; F = 0.15 | **Fr:** M = 0.15; F = 0.18 |**J:** M = 0.16; F=N/S.	

(*continued on next page*)

Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
Jarvinen et al. (1993) [125]	A carotene (μg) M 67 ± 123, F 105 ± 146, β - carotene 1589 ± 1862 2060 ± 2184, gamma carotene 34 ± 38, 48 ± 53 lycopene 602 ± 684 867 ± 964 lutein 1031 ± 457, 895 ± 349	β - carotene (μg/L) men mean 86 ± 78 women 125 ± 94	Linear covariance analysis	
Jilcott et al. (2007) [33]	UC	UC	Significance not stated (n = 200, those with values consistent with supp use excluded). **DRA. F&V vs: carotenoid index,** r = −0.30, p < 0.0001; α-cartoene, r = −0.23, p = 0.0009; β-carotene, r = −0.31, <0.0001; zeaxanthin plus lutein, r = −0.15, p = 0.03; **Fruit vs cryptoxanthin,** r = −0.27, p < 0.0001; **veg vs: α**-carotene, r = −0.33, p= < 0.0001; β-carotene, r = −0.35, p < 0.0001. **FFQ, 5-A-Day method: F&V vs.** β-carotene, r = 0.26, p = 0.02; **Fruit vs.** cryptoxanthin, r = 0.25, p = 0.02; **Veg vs** β-carotene, r = 0.24, p = 0.03; others all p ≥ 0.05. FFQ, Summation method: all p ≥ 0.05	Information on supplement use not collected, therefore those with serum levels typical of supp use were excluded.
Kabagambe et al. (2001) [126]	Mean(SD), μg. **α-carotene:** 24R = 118(70); FFQ1 = 640(792); FFQ2 = 459(442); AVE FFQ = 550(547) **β-carotene:** 24R = 596(351); FFQ1 = 4239(3344); FFQ2 = 3604(2283); AVE FFQ = 3921(2442) **cryptoxanthin**: 24R = 262(172); FFQ1 = 610(603); FFQ2 = 457(498); AVE FFQ = 533(482) **zeaxanthin + lutein:** 24R = 599(292); FFQ1 = 2922 (2892); FFQ2 = 2423 (2265); AVE FFQ = 2672 (2308) **lycopene:** 4R = 916(798); FFQ1 = 5180(3709); FFQ2 = 5249(3637); AVE FFQ = 5215(3108)	not reported - ONLY retinol in plasma	All r (+corrected for day-to-day variation Cr for 24R only).**α-carotene:** 24R: r = 0.25; Cr = 0.33; FFQ1 = 0.32; FFQ2 = 0.28; ave FFQ = 0.36|**β-carotene:** 24R: r = 0.26; Cr = 0.35; FFQ1 = 0.33; FFQ2 = 0.36; ave FFQ = 0.38|, **cryptoxanthin:** 24R: r = 0.25; Cr = 0.43; FFQ1 = 0.53; FFQ2 = 0.55; ave FFQ = 0.58 |, **zeaxanthin + lutein:** 24R: r = 0.32; Cr = 0.43; FFQ1 = 0.28; FFQ2 = 0.26; ave FFQ = 0.27 **lycopene:** 24R: r = 0.30; Cr = 0.45; FFQ1 = 24; FFQ2 = n/s; ave FFQ = 0.26	
Kanetsky et al. (1998) [127]	Median (IQR), μg: cases (n = 32); controls (n = 113). **α-carotene** = 204(24.5−400); 199(54.7 −390) **β-carotene** = 2308 (1270 −4502); 2474 (1424−4368) C**ryptoxanthin** = 79 (28.4−145); 90.7 (36.4−141) **lycopene** = 396 (172−816); 618 (341−1250) **Lutein** = 2209 (1149 −3718); 2657 (1281−5661).	Median (IQR), μg: cases (n = 32); controls (n = 113). α-carotene = 1.1(0.30−3.5); 1.1(0.60−2.8) β-carotene = 7.7 (3.1−19.5); 9.3 (5.1−15.6) cryptoxanthin = 9.1 (6.3−14.1); 9.7 (7.2−13.7) Lutein = 76.1 (64.0−118); 77.2 (62.5−104). lycopene = 32.7 (24.7−54.7); 34.8 (26.5−48.2)	No sig correlations, only when restricted to control women not taking supp (n = 19) r (95%CI), Cases; controls. β-carotene = 0.52 (−0.09 to 0.79)|Lycopene = 0.55 (0.13 −0.81)	
Kant & Graubard et al. (2005) [129]	Not reported in absolute values, only association with 3 dietary scores (Table 3). Pearson's r with Carotene (RE): HEI = 0.20; RFS = 0.31; DDS-R = 0.19; all p < 0.0001	n = 7997. Dietary scores (HEI, RFS, DSS-R) split into quartiles and mean ± SEM reported for each (μmol/L) **serum α-carotene** C1: 0.072 ± 0.002,0.072 ± 0.003, 0.073 ± 0.002C2: 0.083 ± 0.002, 0.077 ± 0.002, 0.085 ± 0.002 C3: 0.093 ± 0.003, 0.084 0.002, 0.092 ± 0.002 C4: 0.118 ± 0.004, 0.114 ± 0.003, 0.119 ± 0.004	All 3 dietary scores were strong ve predictors of all serum carotenoids, except lycopene (sig for RFS & DDS-R only @ p < 0.05)	

		β±SE[2]: 0.001 ± 0.000, 0.009 ± 0.000, 0.012 ± 0.001 **β-carotene** C1: 0.322 ± 0.009, 0.326 ± 0.010, 0.330 ± 0.008 C2: 0.359 ± 0.013, 0.340 ± 0.009, 0.357 ± 0.008 C3: 0.373 ± 0.010, 0.354 ± 0.010, 0.374 ± 0.011 C4: 0.441 ± 0.014, 0.438 ± 0.008, 0.454 ± 0.013 β±SE[2]: 0.003 ± 0.000, 0.022 ± 0.002, 0.035 ± 0.004 **cryptoxanthin** C1: 0.143 ± 0.003, 0.139 ± 0.004, 0.142 ± 0.003 C2: 0.158 ± 0.004, 0.148 ± 0.004, 0.158 ± 0.004 C3: 0.165 ± 0.003, 0.162 ± 0.004, 0.172 ± 0.004 C4: 0.196 ± 0.005, 0.190 ± 0.004, 0.193 ± 0.006 β±SE[2]: 0.001 ± 0.000, 0.009 ± 0.000,0.014 ± 0.001 **Lutein/zeaxanthin** C1: 0.351 ± 0.006, 0.335 ± 0.005, 0.345 ± 0.003C2: 0.367 ± 0.007, 0.343 ± 0.009, 0.372 ± 0.006 C3: 0.386 ± 0.008, 0.370 ± 0.006, 0.389 ± 0.008 C4: 0.411 ± 0.008, 0.424 ± 0.008, 0.413 ± 0.011 β±SE[2]: 0.002 ± 0.000, 0.016 ± 0.001, 0.019 ± 0.004 **Lycopene** C1: 0.440 ± 0.005, 0.443 ± 0.007, 0.443 ± 0.006 C2: 0.456 ± 0.006, 0.433 ± 0.007, 0.439 ± 0.007 C3: 0.443 ± 0.007, 0.446 ± 0.007, 0.442 ± 0.006 C4: 0.449 ± 0.007, 0.456 ± 0.006, 0.466 ± 0.007 β±SE[2]: 0.000 ± 0.000, 0.002 ± 0.001, 0.006 ± 0.002		
Kardinaal et al. (1995) [130]	mg/d, mean(SD): for β-carotene M = 1.73 (0.0.66); F = 1.75 (0.72)	μmol/L, mean (SD): for β-carotene M = 0.41 (0.26); F = 0.63 (0.67)	No sig correlations for β-carotene diet vs plasma (r = 0.15; n = 82) and vs adipose tissue (r = 0.16; n = 74)	
Katsouyanni et al. (1997) [131]	Mean(SD) mg/d. **M:** 24R = 3.6(2.1); FFQ1 = 6.6(4.7); FFQ2 = 7.6(6.9). **F:** 24R = 2.8 (1.2); FFQ1 = 9.0 (5.4); FFQ2 = 6.7 (4.4).	UC	**24R** = R = 0.22 (n = 61); **FFQ1** = 0.03 (n = 59); **FFQ2** = −0.11 (n = 58)	
Kiely et al. (1999) [132]	Mean (SD); μg/d. Total = 3213 (1703); S = 3464(1885); NS = 2977(1503)	**μmol/L, mean (SD):** Total = 0.22(0.1); S = 0.22(0.1); NS = 0.22(0.1). **Plasma β-carotene levels of 40 neonates also reported:** total 0.04(0.03); S = 0.058 (0.04); NS = 0.03 (0.02)	Smokers, r = 0.41, p = 0.015. Non-smokers, r = 0.28, p = 0.12	
Knutsen et al. (2001) [133]	Mean (SD), μg. Reported including and excluding supplements. **Including supps;** **Black:** total = 6361.8(18317.3); (n = 61) = 6991.1(22882.8); (n = 36) = 5295.5 (4556.7). **White:** Total = 6161.9(6966.9); F(n = 56) = 6267.7(6480.9); M(n = 40) = 6013.9(7678.5). **Excluding supps; Black:** total = 5963.4 (18292.3); F(n = 56) = 6609.0 (22857.8); M(n = 40) = 4869.4 (4489.1). **White:** total = 5142.3(6239.1); F(n = 56) = 4830.6(4968.2); M(n = 40) = 5578.7(7725.1)	Mean (SD), μg/dl. **Black:** total = 175.1 (74.3); F = 167.9(78.1); M = 187.7 (66.3). **White:** total = 164.2(63.5); F = 165.6 (67.5); M = 162.3 (58.4)	**Black:** 24 h recall, without supp (n = 83) r = 0.351; including supp users (n = 97) r = 0.380; FFQ, without supp (n = 60) r = 0.393, with supp (n = 97) = 0.340. **White:** 24 h R, without supp (n = 66) r = 0.351, with supp (n = 96)r = 0.380; FFQ, without supp (n = 60) r = 0.291, with supp (n = 96) r = 0.284.	Highly educated population
Kobayashi et al. (2011) [134]	Mean ± SD (μg) **Raw database** − α −carotene M:997 ± 1994 F:826 ± 1324, β − carotene M: 3413 ± 5041 F: 3309 ± 4114, lycopene M:3408 ± 3756 F:3877 ± 4217, **cooked database -** α -carotene	**Serum** (mg/ml): α -carotene M:0,07 ± 0,04 F:0,10 ± 0,05, β - carotene M: 0,32 ± 0,24 F: 0,57 ± 0,37, lycopene M:0,11 ± 0,05 F:0,13 ± 0,06	P-values not provided. Values with 95%CI not crossing zero presented: **Raw database -**β - carotene M: 0.24(0.04−0.44) F: 0.21(0,01−0.41), lycopene M:0,30(0.09 −0.50) F:0.35(0.15−0.56). **cooked database -**α -carotene M:0.22(0.02-0.43), β - carotene	Not adjusted for smoking or alcohol intake

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Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
	M:1095 ± 1800 F:893 ± 1164, β - carotene M: 3484 ± 7137 F: 3443 ± 6007, lycopene M: 2835 ± 3690 F:3126 ± 3661,		M: 0.24(0.02−0.41), lycopene M:0.37(0,18 −0.57) F:0.37(0,16−0.57)	
Le Marchand et al. (1994) [135]	Mean value (μg/ᴅ) − Baseline (3months): α -carotene 1398(1598); β - carotene 4357(9943); β - cryptoxanthin 318(370); lutein 1637(5126); lycopene 2407(13071); total carotenoids 10117(30108)	Mean value (μg/ʟ) - Baseline(3months): α -carotene 62(92); β - carotene 461(618); β - cryptoxanthin 245(284); lutein 291(352); lycopene 199(242); total carotenoids 1552(1964)	α -carotene 0.25; lutein 0.41; β - carotene 0.50; β - cryptoxanthin −0.04; total carotenoids 0.41	Not 'healthy' population (former cancer pts)
Lin et al. (2010) [136]	Mean (SD), ug/d: **α -carotene** COPD 221(361) HC 333(422); **β - carotene** COPD 3210(1904) HC 4291(2208); **lutein** COPD 2278(1843) HC 3370(2370); **lycopene** COPD 525(669) HC 1281(1144); **total carotenoids** COPD 6234(3480) HC 9271(4838)	Mean (SD), μg/ml: α -carotene COPD 0.07(0.83) HC 0.44(0.76); β - carotene COPD 0.35(0.14) HC 0.62(0.58); lutein COPD 0.05(0.58) HC 0.07(0.04); lycopene COPD 0.02(0.01) HC 0.04(0.08); total carotenoids COPD 0.49(0.20) HC 1.12(0.98)	α -carotene 0.382, p = 0.008; total carotenoids 0.242, p = 0.006	Complete data not shown as not primary outcome
Liu et al. (1992) [137]	Mean (SD): **β** -carotene μg FFQ 2470.11(2137.15)	NR	UC - appears corrected associations for **β** -carotene only. FFQ b-carotene 0.23.	Patient population and result reporting unclear
Ma et al. (2009) [138]	Baseline mean (SD), mg/d: β -carotene 3.5(2.5) lutein 2.4(2.0);	serum lutein mean (SD), μmol/L: 0.34(0.12)	baseline lutein 0.56 (p < 0.01); plateau lutein concentration in serum as a linear function of dosage r = 0.71 (p < 0.001); baseline serum lutein as predictor of change in serum lutein r = −0.41	Small n
Machefer et al. (2007) [34]	Reported as % of DRI. 57.9% had intake >150%DRI	Mean(SD), μmol/L: B-carotene 0.91(0.14)	**β** -carotene 0.52, p < 0.05;	Small n; not general population
Maleksha et al. (2006) [139]	**24 h recalls** β -carotene, μg: M 90(107) F 66(78); **FFQ** β -carotene: M 156(184) F 156(21)	**First measurement:** α-carotene 0.04(0.02),β -carotene 0.164(0.12), cryptoxanthin 0.04(0.03); lutein 0.31(0.16), zeaxanthin 0.053(0.02), lycopene 1.34(0.75), **second measurement:** α-carotene 0.05(0.03),β-carotene 0.198(0.15), cryptoxanthin 0.13(0.19)lutein 0.35(0.2), zeaxanthin 0.068(0.04), lycopene 1.56(0.64),	β-carotene only reported with mean of 12 24 h recalls: 0.35; mean 4 FFQs: 0.37	Did not account for smoking or gender differences
Mandel et al. (1997) [140]	All subjects (μg/d) β carotene 400(78)	UC	β carotene 0.16 Non supplement users 0.20	Small n; uneven gender ratio
Margetts et al. (1993) [141]	Carotene (μg):**Males:** non-smoker 2615(2456, 2773), light smoker 1936(1705, 2168), heavy smoker 2233 (1899, 2568); **Females:** non-smoker 2359(2192, 2526), light smoker 1766(1585, 1948), heavy smoker 1601(1321, 1881)	NR	Dietary carotene with serum B-carotene r = 0.26, p < 0.01	Methods not adequately reported; gender analysis not reported; non-smokers not separated into never and ex-smokers.
McNaughton et al. (2005) [142]	μg, mean(SD): **WFR:** α -carotene 1601(856),β -carotene 4067(2271), β - cryptoxanthin 213(214), lutein 523(264), lycopene 2336(1464), total carotenoids 8741(2937); **FFQ:** α -carotene 4234(2275), β -carotene 10002(4954),β -cryptoxanthin 626(528), lutein 1631(1172), lycopene	Serum μmol/l, mean(SD): α -carotene 0.11(0.08), β - carotene 0.62(0.59), β - cryptoxanthin 0.25(0.35), lutein 0.36(0.45), lycopene 0.17(0.12), total carotenoids 1.51(1.23)	[1] ***Correlation*, WFR and biomarker:** β -cyptoxanthin 0.42* [2]. ***validity coefficients (NB: UC if stat signif)*FFQ:** α -carotene 0.85, β - carotene 0.55, lutein 0.19, lycopene 0.62, total carotenoids 0.55; **WFR:** α -carotene 0.45, β - carotene 0.65, lutein 1.0, lycopene 0.23, total carotenoids 0.64; **Biomarker:** α -carotene 0.42, β - carotene 0.40, lutein 0.16, lycopene 0.30, total carotenoids 0.51	Measures not collected at same time point nor reflect same time frame; small n for analysis by gender, age, etc.

	3813(2299), total carotenoids 20306(8514)			
Meyerhardt et al. (2005) [143]	NR	Median (95% CI), mmol/L: α -carotene 71(8−467), β - carotene 277(28−1354)	Multi-variate adjusted: α -carotene 0.36, β - carotene 0.33, lutein + zeaxanthin 0.39, β - cryptoxanthin 0.44 lycopene 0.34,	Fasting prior to blood collection not consistent between patients; gender NR
Michaud et al. (1998) [144]	*Log-transformed values mean(SD), unadjusted, mg/d* [1] ***FFQ1-M:***α -carotene 1011(1019), β - carotene 5004(3313),lutein 3784(2382), β - cryptoxanthin 94(82); lycopene 11119(6221), ***F:***α -carotene 919(712), β - carotene 5100(2997),β - cryptoxanthin 75(72).lutein 4438(3674), lycopene 11270(7212), (***2) FFQ2-M:***α -carotene 910(771), β - carotene 4888(2873), β - cryptoxanthin 77(56); lutein 2803(2038), lycopene 10497(6177), ***F:***α -carotene 884(675), β - carotene 4755(2574),β - cryptoxanthin 67(68)lutein 3984(2690), lycopene 10405(7278),	Mean(SD), mg/dl −**Males:** α -carotene 612(5,54, β - carotene 24,67(15,58), β - cryptoxanthin 13.29(6.54); lutein 15,68(5,62), lycopene 43.9(20.17), **Females:** α -carotene, 6.71(5.24) β - carotene 30.87(20.14),β - cryptoxanthin 12.26(6.27) lutein 15.38(6.18), lycopene 40.77(17.11),	*Correlations adjusted for TEI, using adjusted plasma concentrations* (***1) FFQ1*** - ***Males:*** α -carotene 0.36, β - carotene 0.30, β - cryptoxanthin 0.39; lutein 0.30, lycopene 0.35, ***Females:*** α -carotene 0.40, β - carotene 0.21, β - cryptoxanthin 0.29. lutein 0.27, lycopene 0.18, (***2) FFQ2*** - ***Males:*** α -carotene 0.48, β - carotene 0.31, β - cryptoxanthin 0.40; lutein 0.38, lycopene 0.46, ***Females:*** α -carotene 0.47, β - carotene 0.30, β - cryptoxanthin 0.31 lutein 0.23, lycopene 0.18,	Correlations in FFQ2 may have been raised due to improved diet reporting following FFQ1 and 2× DR. Women analysis may be affected by menopausal status
Mohammadifard et al. (2011) [39]	Whole fruits and vegetables	NR	T1: Fruits 0.44, Citrus 0.33, Other fruits 0.44, Dry fruits/nuts 0.27, Fruit juices 0.29; Vegetables 0.41, Root vegetables 0.42, Onions 0.41, Leafy veges 0.39, Non-leafy veges 0.37, Pickles 0.27, Dry veges 0.24; Total fruit & veges 0.47. T2: Fruits 0.42, Melons 0.35, Other fruits 0.45, Dry fruits/ nuts 0.31, Fruit juices 0.3; Veges 0.43, Root veges 0.38, Onion 0.35, Leafy veges 0.46, Non-leafy veges 0.38, Pickles 0.28, Dry veges 0.28; Total fruits & veges 0.45	Included smokers and supplement takers and not adjusted or reported
Natarajan et al. (2006) [145,146]	Total carotenoids, mean(SD), mg/d: **24-hr recalls** baseline 20.21(34.67), 12 months 18.78(27.35); **FQ** baseline 24.88(27.97), 12 months 25.31(32.50)	Total carotenoids, mean(SD), mmol/L: baseline 2.40(1.56), 12months 2.34(1.40)	*Pearson correlations*: with 24-hr recall baseline r = 0,45, 12months r = 0,40; with FFQ baseline r = 0,35, 12months r = 0,31. ***Model-based estimate of correlation between dietary measure and true intake: 24-hr recall*** α -carotene 0.45, β - carotene 0.52, β - cryptoxanthin 0.33; lutein 0.29, lycopene 0.27, total carotenoids 0.44, ***FFQ*** α -carotene 0.45, β - carotene 0.47, β - cryptoxanthin 0.36; lutein 0.21, lycopene 0.24, total carotenoids 0.39, ***plasma biomarker*** α -carotene 0.85, β - carotene 0.87, β - cryptoxanthin 0.83 lutein 0.86, lycopene 0.76, total carotenoids 0.86,	Only total carotenoids reported; population not adequately described; unadjusted for confounders
Neuhouser et al. (2007) [148]	Proportion who reported having a food in their house non Hispanic/Hispanic/ native American Orange Juice73.4/73.3/ 61.5Tomato/tomato products 96.8/ 98.1/96.2Deep yellow or orange fruits 77.1/86.0/79.8Bright orange/dark green vegetables 95.4/92.4/74.0	NR	Total sample. **Household inventory:** α -carotene 0.12, β - carotene 0.14,β - cryptoxanthin 0.23; total carotenoids 0.12, **5 A DAY fruit & veg servings**: α -carotene 0.15, β - carotene 0.17, β - cryptoxanthin 0.17	NR of smoking or supplement use

(*continued on next page*)

Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
Newby et al. (2003) [30]	Mean DQI-R 67.2 ± 14.3	α carotene (μmol/l) 1.52 ± 0.75 β 2.98 ± 0.61 lutein 2.70 ± 0.38 lycopene 3.67 ± 0.41	DQI- R from FFQ with α carotene 0.43 β carotene0.35 lycopene 0.17 lutein 0.31	Men only
Nolan et al. (2007) [147]	MEAN(sd), mg/d: LUTEIN 1.399(0.79), Zeaxanthin 0.199(0.117)	Mean(SD), μg/ml: Lutein 0.087(0.042), Zeaxanthin 0.026(0.016)	***Lutein*** (ug/ml): absolute dietary (mg/d) 0.286, energy-adjusted dietary (residuals method) 0.301, nutrient density (mg/kcal) 0.300. ***zeaxanthin*** (ug/ml): absolute dietary (mg/d) 0.249, energy-adjusted dietary (residuals method) 0.254, nutrient density (mg/kcal) 0.258.	Basic demographics not adequately reported.
Ocké et al. (1997) [149]	β - carotene mean(cv%), mg: **Recalls** – M 1.62(43.9), F 1.22(48.7); **FFQ** – M 1.88(48.0), F 1.51(40.3)	NR (serum)	NB: does not indicate significance level [1]. FFQ Unadjusted β - carotene: Males −0.17 (non-smokers −0.17), Females 0.14 (non-smokers 0.12); Energy adjusted β - carotene (residuals method): Males −0.15 (non-smokers −0.08), Females 0.18 (non-smokers 0.18) [2]. recall: males 0,14, females 0,15.	Low initial response rate (25%); demographics not provided; lab CV for B-carotene 12,5%
Olafsdottir et al. (2006) [150]	β - carotene (ug) **FFQ:** absolute intake 982(630), nutrient density 1268(762); **24-hr recall:** absolute 1296(1112), nutrient density 1450(1362). *Nutrient density = ug/10 MJ	β - carotene, μmol/L, mean(SD): 0.4(0.3)	Plasma β - carotene with 24-hr recall absolute β - carotene intake r = 0.301, p = 0.029	Underpowered due to small sample size; self-reported height and weight (known to be underestimated in females and obese)
Palli et al. (1999) [151]	Carotene μg/d, mean(SE): M 2690.8(47.9), F 2786.6(53.6)	Carotene, μg/dl, mean(SE): M 32.7(1.2), F 45.7(1.3)	M: 0.27, F: 0.23; p-value NR	Unadjusted for BMI; individual carotenoids NR; supplement use data not collected
Pierce et al. (2006) [152]	Whole foods only, no values reported	*Log transformed*(**μmol/L) Mean (SD). Intervention group: Baseline, [12mo]:** α -carotene 0.204 (0.230), [0.597 (0.686)]; β - carotene 0.865 (0.874), [1.466 (1.416)]; cryptoxanthin 0.171 (0.155), [0.179 (0.159)]; lutein + zeaxanthin 0.380 (0.200), [0.459 (0.243)]; lycopene 0.653 (0.345), [0.739 (0.368)]; Total 2.272 (1.294), [3.440 (2.320)]. **Comparison group: Baseline, [12mo]:** α -carotene 0.204 (0.213), [0.203 (0.219)]; β - carotene 0.914 (1.065), [0.868 (0.937)]; cryptoxanthin 0.178 (0.175), [0.177 (0.157)] lutein + zeaxanthin 0.376 (0.204), [0.381 (0.213)]; lycopene 0.655 (0.344), [0.650 (0.340)]; Total 2.327 (1.470), [2.279 (1.371)]	**Full model β coefficients: Juice** α -carotene 0.083 (P < 0.001), β - carotene 0.011 (P < 0.001), lutein + zeaxanthin 0.005 (P < 0.05), lycopene 0.018 (P < 0.001). **Food:** α -carotene 0.074 (P < 0.001), β - carotene 0.135 (P < 0.001), lutein + zeaxanthin 0.096 (P < 0.001), lycopene 0.034 (P < 0.001). **Supplement:** β - carotene 0.040 (P < 0.001), lutein + zeaxanthin 0.017 (P < 0.001)	Actual dietary level of nutrients not calculated, correlations between plasma levels and food, juice and supplement intake not assessed against covariates individually, correlations only performed for 2346 of 2922 participants
Pollard et al. (2003) [153]	*Excluding supplements. Geometric means* **(mg/day) mean (range)** **T1:** β-carotene: 1635 (1338.0–1988.0), carotene equiv: 2316.7 (1955.3 –2744.9). **T2:**β-carotene: 460.8 (221.5–958.6), carotene equiv: 1281.3 (944.6–1738.0).	*Geometric means. Values log transformed* **(nmol/L) mean (range)T1:** β-carotene 495.3 (420.9–582.9), cryptoxanthin 258.9 (219.1–305.9), lutein 556.6 (501.2–618.2), lycopene 469.2 (396.9–554.8). **T2:** β-carotene 461.9 (385.3–553.6), cryptoxanthin 295.6 (241.6–361.5), lutein 525.6 (466.8–591.8), lycopene 404.8 (330.4–496.1).	(After adjustment for age, BMI and total calorific intake including alcohol) **Four day diary record:** When total β-carotene intake from all sources was doubled there was 31% increase in plasma β-carotene (P < 0.01). **24 h recall:** When carotene equiv from all sources was doubled, plasma lutein rose by 13% (P < 0.01) and plasma lycopene rose by 15% (P = 0.04)	Only dietary β-carotene and carotene equivalents assessed. Unsure why dietary carotenoids doubled to find effect??

Polsinelli et al., 1998 [154]	**Mean ± SD:** Vegetable (servings) 2.6 ± 1.3, Fruit servings 2.5 ± 1.3	**(μmol/L) Mean ± SD.** α -carotene 0.28 ± 0.40, β - carotene 0.87 ± 1.03, β-cryptoxanthin 0.16 ± 0.89, lutein 0.51 ± 0.27, lycopene 0.57 ± 0.22, Total 2.40 ± 1.52	**Vegetables** α -carotene 0.62, lutein 0.58 (both $p < 0.01$). **Fruit** α -carotene 0.64 ($p < 0.01$) lutein 0.44 ($p < 0.05$). **F + V** α -carotene 0.73 ($p < 0.01$), β - carotene 0.48 ($p < 0.05$), lutein 0.60 ($p < 0.01$), total 0.48 ($p < 0.05$)	Very small n; actual dietary carotenoids not calculated; correlations not assessed for confounders
Porrini et al. (1995) [155]	(μg/d) mean (SD) β-carotene: **FFQ:** 3569.5 (1308.8). **7 day FR:** 2653.2 (1245.2)	(μg/L) mean (SD). β-carotene 391 [192].	β-carotene $r = 0.439$, $P = 0.008$ (seven day food record)	Results not assessed for confounding variables. Small n. Unequal number of M to F
Rao et al. (2007) [156]	**Total average** Lycopene 5.09 ± 0.95 mg/day. **Average Lycopene by quartiles (mg/day)** Quartile 1: 1.76 ± 0.76, quartile 2: 3.68 ± 0.94, quartile 3: 3.03 ± 1.09, quartile 4: 7.35 ± 0.80.	**Total average** Lycopene 247.50 ± 32.56 (nM), 4.01 ± 0.51 [(nM)/kg]. **Average lycopene by quartiles (nM) & [(nM)/kg]** Quartile 1: 74.99 ± 15.09 & 1.13 ± 0.25, quartile 2: 165.60 ± 12.04 & 2.62 ± 0.11, quartile 3: 234.5 ± 24.15 & 4.04 ± 0.22, quartile 4: 502.8 ± 47.39 & 8.11 ± 0.63.	Serum lycopene (nM/kg) positively associated with average lycopene intake in quartiles 2, 3 and 4 with 2.62 ± 0.11, 4.04 ± 0.22 and 8.11 ± 0.63 respectively ($r^2 = 0.46$, $p < 0.005$)	No mention of whether lycopene intake was related to serum levels without adjusting for body weight. Method of dietary assessment not clear.
Re et al. (2003) [157]	**Weight of tomato product consumed (g/d). Mean (SD).** Free-living 37.6 [43]. Institution 29.2 (33.0). **Type of tomato product consumed (%):** **Free living:** None 29; Raw 26; processed only 7; TCP 11; raw & processed 8; raw &TCP 11; processed & TCP 3; Raw, processed and TCP 5. **Institution**: None 24; Raw 16; processed only 11; TCP 12; raw & processed 10; raw &TCP 8; processed & TCP 10; Raw, processed and TCP 9.	**(μmol/L) Mean (SD).** Free living 0.27 (0.20), Institution 0.16 (0.13). ($P < 0.0001$ between groups)	*Log transformed value* **Relation between weight of tomato products and plasma lycopene. Beta coefficient (s.e)** Free living 0.07 (0.01), $P < 0.001$. Institution 0.10 (0.01), $P < 0.001$. **Pearson's:** free living: $r = 0.36$, $P < 0.0001$ and institution $r = 0.39$, $P < 0.0001$. **Relation between type of tomato product consumed and plasma lycopene. Beta coefficient (s.e) Free living** Raw 0.41 (0.07); processed only 0.52 (0.10); TCP 0.58 (0.09); raw & processed 0.70 (0.10); raw &TCP 0.61 (0.08); processed & TCP 0.73 (0.14); Raw, processed and TCP 0.72 (0.11) ALL $P < 0.0001$. **Institution:** Processed only 0.50 (0.16) $P = 0.002$; TCP 0.58 (0.18) $P = 0.001$; raw & processed 0.79 (0.18) $P < 0.0001$; raw &TCP 0.67 (0.20) $P = 0.0010$; processed & TCP 0.89 (0.19) $P < 0.0001$; Raw, processed and TCP 1.20 (0.19) $P < 0.0001$.	Actual dietary intake of carotenoids not measured; groups not comparable on a number of sociodemographic parameters; not all participants provided a blood sample.
Resnicow et al. (2000) [158]	(μg/day) **36-item FFQ** [mean(SD)] α -carotene 532 (661), β - carotene 3650 (3041), cryptoxanthin 100 [90], lutein 2628 (1975), lycopene 2065 (2913). **Single 24 h recall**: α -carotene 401 (1595),β - carotene 2867 (5948), cryptoxanthin 97 [136], lutein 3270 (6752), lycopene 2787 (6341). **Three 24hr recall**: α -carotene 303 (418), β - carotene 2578 (3089), cryptoxanthin 93 [89], lutein 3033 (4077), lycopene 2200 (2612)	(μg/dL) ($n = 813$) α -carotene 4.1 (6.1), β - carotene 23.6 (25.3), cryptoxanthin 9.4 (6.2), lutein 22.4 (10.2), lycopene 18.0 (8.8)	**36- item FFQ:** α-carotene 0.40, β-carotene 0.39, Cryptoxanthin 0.35, Lutein 0.21, total 0.33, total without lycopene 0.37 (all $p < 0.01$). **Single 24 h recall:** α-carotene 0.29, β-carotene 0.25, Cryptoxanthin 0.34, Lutein 0.19, total 0.31, total without lycopene 0.39 (all $p < 0.01$). **Three 24 h recall:** α-carotene 0.31 ($p < 0.01$), Cryptoxanthin 0.48 ($p < 0.01$), Lutein 0.27 ($p < 0.05$), total 0.24 ($p < 0.05$), total without lycopene 0.40 ($p < 0.01$)	Different number of participants completed the assessments: eg FFQ $n = 1002$, Single recall $n = 414$, 3 recalls $n = 105$, serum levels $n = 813$. The recall subset was significantly different to remaining subjects re college and alcohol use.
Rifas-Shiman et al. (2001) [159]	Actual intake of carotenoids not reported	Actual plasma levels of carotenoids not reported	Correlation between plasma conc and PrimeScreen results: β-carotene ($r = 0.43$) and lutein/zeaxanthin ($r = 0.43$). No mention of significance level. These correlations similar to those between the SFFQ and plasma levels.	Actual dietary and plasma levels of nutrients not reported. Source of plasma levels and biochemical method not reported. PrimeScreen does not assess total diet

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Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
Ritenbaugh et al. (1996) [160]	Total study population (mg/day) **Mangels'** α-carotene 0.55 ± 0.45, β-carotene 3.45 ± 2.07, lutein 1.89 ± 1.47. lycopene 0.43 ± 0.29, **Block's** α-carotene 0.60 ± 0.64, β-carotene 2.87 ± 2.24, lutein 2.13 ± 1.97. lycopene 0.40 ± 0.31,	(μmol/L) α-carotene 0.12 ± 0.11 (n = 144), β-carotene 0.43 ± 0.36 (n = 157), lutein 0.18 ± 0.09 (n = 92). lycopene 0.63 ± 0.28 (n = 144),	β-carotene: Mangels' data base more strongly correlated to plasma values than Block's 0.441 and 0.317 respectively (P = 0.015)	Details of studies included were not described. Other demographic and confounders information besides age, BMI & smoking status not reported.
Rock et al. (1997) [161]	β-carotene. (μg/d) White: 2599 ± 184. African American: 1749 ± 204	(μmol/L) **White:** α -carotene 0.004 ± 0.007,β -carotene 0.218 ± 0.038, β - cryptoxanthin 0.079 ± 0.010, lutein 0.158 ± 0.017, lycopene 0.359 ± 0.031 Total 0.857 ± 0.068, Total minus lycopene 0.498 ± 0.054 **African-American:** α -carotene 0.040 ± 0.012, β - carotene 0.288 ± 0.054, β - cryptoxanthin 0.097 ± 0.017, lutein 0.266 ± 0.032, lycopene 0.396 ± 0.054 Total 1.086 ± 0.118, Total minus lycopene 0.690 ± 0.088	B carotene 0.18	Haemodialysis patients so cannot generalise. Unequal number of participants in groups.
Rock et al. (1999) [162]	NR	*Log transformed*(μmol/L) mean (SD). **Females:** -carotene 0.06 (0.06),β-carotene 0.23 (0.20),β-cryptoxanthin 0.09 (0.06), lutein 0.22 (0.10), zeaxanthin 0.07 (0.04). lycopene 0.55 (0.34), **Males:** α-carotene 0.04 (0.05), β-carotene 0.18 (0.15), β-cryptoxanthin 0.08 (0.06), lutein 0.22 (0.10), zeaxanthin 0.07 (0.04)lycopene 0.58 (0.40)	**Association between total dietary carotenoids and individual serum carotenoids: Reported as % Change (95% CI)** α-carotene 2.9 (2.4, 3.5), β-carotene 2.9 (2.4,3.4), β-cryptoxanthin 0.8 (0.5, 1.0) Lutein 0.8 (0.4, 1.3) Lycopene 1.8 (1.2, 2.5), and **All P = 0.05**	No direct association between individual dietary carotenoids and individual serum carotenoids assessed.
Rock et al. (2001) [163]	**(μg/day) Median (range). Control: Baseline, [6 mo]** α-carotene 306 (7−1707), [310 (84−1604)]; β-carotene 1890 (651−9987), [2422 (454−7294)]; β-cryptoxanthin 10 [1−108], [20 (1−3838)]; lutein/zeaxanthin 1028 (211−4653), [1166 (260−3594)]; lycopene 2057 (510−8473), [3831 (377−8173)], total 6670 (1666−24679), [7763 (1184−17936)]. **Intervention: Baseline, [6mo]:** α-carotene 330 (24−1312), [1423 (88−7744)]; β-carotene 2394 (444−5780), [9531 (876−30994)]; β-cryptoxanthin 12 [1−154], [28 (1−201)]; lutein/zeaxanthin 788 (310−6340), [2338 (271−6159)]; lycopene 2372 (675−12486), [3899 (1287−12303)]; total 6670 (1666−24679), [18923 (2530−44390)].	*Log transformed, not cholesterol adjusted***(μmol/L) Mean ± SE. Control: Baseline, [6mo]** α-carotene 0.13 ± 0.02, [0.12 ± 0.02]; β-carotene 0.46 ± 0.09, [0.39 ± 0.07; β-cryptoxanthin 0.19 ± 0.03, [0.16 ± 0.03]; lutein/zeaxanthin 0.41 ± 0.05, [0.39 ± 0.04]; lycopene 0.75 ± 0.09 [0.75 ± 0.08]; total 1.94 ± 0.20, [1.83 ± 0.16]. **Intervention: Baseline, [6mo]** α-carotene 0.11 ± 0.01, [0.84 ± 0.02]; β-carotene 0.47 ± 0.09, [1.55 ± 0.30]; β-cryptoxanthin 0.20 ± 0.02, [0.31 ± 0.03]; lutein/zeaxanthin 0.46 ± 0.03, [0.55 ± 0.06]; lycopene 0.79 ± 0.07 [0.65 ± 0.07]; total 2.04 ± 0.13, [3.90 ± 0.56].	From Regression models α-carotene 0.30 β-carotene 0.16 β-cryptoxanthin 0.09 lutein/zeaxanthin 0.06 lycopene 0.01 total carotenoids 0.14	Limited analysis of assoc between dietary and plasma carotenoids. Small n. Groups homegeneity.
Rock et al. (2002) [164]	*Log transformed* **(μg/day) Cross-section Mean (SD):** Lutein + Zeaxanthin 1347 (891). **Cohort Mean ± SD:** 1367 ± 829 at baseline and 1345 ± 831 at 1 year	*Log transformed* **(μmol/L) Cross-section Mean (SD):** Lutein 0.226 (0.120), Zeaxanthin 0.071 (0.039). **Cohort Mean ± SD:**	**Cross-section:** For every 10% increase in estimated dietary lutein + zeaxanthin was assoc with 2.4% increase in serum lutein, P < 0.05 (partial correlation coefficient 0.24) and 1.2% in serum zeaxanthin, P < 0.05 (partial correlation coefficient 0.11).	Difference in demographic characteristics between cross-section and cohort not reported. No correlation (Pearson or Spearman) conducted.

		Lutein 0.225 ± 0.111 at baseline and 0.259 ± 0.125 at 1 yr.	**Cohort:** Every 10% change in dietary lutein + zeaxanthin intake, 1.1% change in serum lutein (no mention of significance)	
Roidt et al. (1988) [173]	**(IU) Mean (SD)** Total dietary carotenoids: 8784 (10740), β-carotene: 7221 (8995), other dietary carotenoids: 1563 (1763)	**(ng/ml) Mean (SD)** α-carotene 42 [35], β-carotene 219 (203)	**Correlations for serum β-carotene:** Total dietary carotenoids 0.21, dietary β-carotene 0.21, other active dietary carotenoids 0.19 (all $p < 0.001$). **Correlations serum α-carotene:** Total dietary carotenoids 0.26, dietary β-carotene 0.25, other active dietary carotenoids 0.25 (all $p < 0.001$).. **Regression coefficient (SE). Serum β-carotene** Dietary β-caroten 0.13 (0.04) (Significance 0.002). **Serum α-carotene** Dietary β-carotene 0.24 (0.05) (significance 0.000)	Small n; correlation with separate confounders not performed; dietary carotenoids other than β-carotene grouped together; study over 20 years old
Romieu et al. (1990) [165]	**(IU/day) Mean (SD)** β-carotene 9245 (7474)	**(μg/dl) Mean (SD)** β-carotene 28.1 (26.5)	**Halving (n=189).** All food 0.38, all foods (calorie adjusted) 0.40, Cumulative % method 0.42, Bivariate regression 0.42, stepwise regression 0.42 ALL $p < 0.0001$. **Cross validation (n = 370).** All food (calculated intake) 0.35, all foods (calorie adjusted) 0.37, Cumulative % method 0.43, Bivariate regression 0.43, stepwise regression 0.42 ALL $p < 0.0001$.	Small n; article over 20 years old; actual dietary carotenoids not assessed
Romieu et al. (1999) [166]	*Log transformed* **Mean (SD) (μg/day)** **24 h recalls:** α-carotene 185 (291), β-carotene 1079 (849), utein + zeaxanthin 496 (337), lycopene 1190 (573), total carotene 3122 (2611).**FFQ1:** α-carotene 144 [125],β-carotene 1257 (812), lutein + zeaxanthin 998 (574), lycopene 1212 (1108), total carotene 3626 (2320). **FFQ2:** α-carotene 156 [152], β-carotene 1165 (724),lutein + zeaxanthin 875 (594), lycopene 1020 (1097), total carotene 3260 (1784)	*Log transformed* **Mean (SD) (μg/L)** α-carotene 39.5 (27.6), β-carotene 253.0 (166.0), lutein 187.0 (70.0), zeaxanthin 73.1 (30.1) lycopene 283.0 (127.0),	Pearson correlations: **FFQ1:** α- carotene 0.37 ($p = 0.001$), β-carotene 0.33 ($p = 0.015$), total carotene 0.38 ($p = 0.001$). **FFQ2:** α-carotene 0.33 ($p = 0.001$), total carotene 0.27 ($p = 0.015$). **Diet recalls:** α-carotene 0.21 ($p = 0.05$).	Small n. 24 h recalls were collected every three months whereas FFQ were administered only at baseline and at 1 yr and blood sample only taken at 3months and 9 months.
Russel Breifel et al. (1985) [29]	Total dietary carotene index (IU/day) total sample of men 6359 ± 296	Plasma carotenoids (μg/dl) 178.8 ± 3.8	0.25 (0.11−0.38) all sample subsample $r = 0.21$	Men only
Ryden et al. (2012) [167]	Actual amount of dietary carotenoids not reported, high carotenoid F + V only	**Median (interquartile range). (μmol/L) Men:** α-carotene 0.08 (0.05−0.12), β-carotene 0.26 (0.18−0.39), β-cryptoxanthine 0.07 (0.04−0.12), lutein (+zeaxanthin) 0.25 (0.18−0.31), lycopene 0.34 (0.19−0.47). Total carotenoid 1.03 (0.77−1.33)**Women:** α-carotene 0.13 (0.09−0.26), β-carotene 0.45 (0.30−0.73), β-cryptoxanthine 0.12 (0.08−0.18), lutein (+zeaxanthin) 0.28 (0.20−0.36), lycopene 0.37 (0.25−0.49)Total carotenoids 1.44 (1.11−1.94)	**Total dietary carotenoid and plasma carotenoid spearman rank correlation coefficients:** α-carotene 0.35, β-carotene 0.33 β-cryptoxanthine 0.39, Total 0.35, (all $P < 0.001$), Lutein 0.13 ($P < 0.05$)	Small n; individual dietary carotenoid levels not measured, no mention of how FFQ was analysed. Significant differences in certain demographics between genders.
Sauvageot et al. (2013) [174]	Median (IQR) μg/day Women β-carotene 3818.6 (2597.6,5464.4)Men 3655 (2334.6, 5392)	Median (IQR) (mg/L) β-carotene Women 0.23 (0.12,0.37) Men 0.15(0.08,0.24)	β-carotene men 0.18 Women 0.22 ($P < 0.001$)	Assessed β-carotene only
Stallone et al. (1997) [168]	Exact values not reported, shown by employment grade on bar chart and separated into 3 categories: all data, low energy reporters (LER) excluded and energy adjusted	Actual plasma levels of carotenoids not reported	**(Adjusted for age and employment grade)** **β-carotene + dietary carotenoids.** **All data:** Men 0.24 ($P \leq 0.01$), Women 0.17 ($P \leq 0.05$). **LER excluded:** Men 0.32 ($P \leq 0.001$).	Results difficult to interpret from bar graph

(*continued on next page*)

Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
Sasaki et al. (2000) [169]	**Crude values: (μg) Mean ± SD** **Men:** α- carotene 181 ± 185, β-carotene 2253 ± 1632, total carotene 2514 ± 1803 **Females:** α- carotene 185 ± 130, β-carotene 2073 ± 1451, total carotene 2322 ± 1594. **Energy density: (μg/4.184 kJ) Mean ± SD** **Men:** α- carotene 77 ± 58, β-carotene 969 ± 517, total carotene 1082 ± 571. **Female:** α- carotene 94 ± 59, β-carotene 1036 ± 603, total carotene 1161 ± 660	**VALUES FOR ONLY 42 OF 44 WOMEN (μmol/L) Mean ± SD.** **Men:** α- carotene 0.18 ± 0.11, β-carotene 0.41 ± 0.20, total carotene 0.59 ± 0.30. **Female:** α- carotene 0.16 ± 0.08, β-carotene 0.45 ± 0.22, total carotene 0.61 ± 0.29	**Crude values Men:** α- carotene 0.43, β-carotene 0.40, total carotene 0.44 (all $p < 0.01$). **Women:** α- carotene 0.42 ($p < 0.01$), β-carotene 0.60 ($p < 0.001$), total carotene 0.56 ($p < 0.001$).	Small n; the nutrients derived from supps not included; 2 women excluded from carotenoid analysis due to extremely high serum carotene concentrations and these two women were not assessed to determine if significantly different from the rest of the women in terms of demographics.
Satia et al. (2009) [170]	**(μg) Median (25th−75th percentile) Whites FFQ, [diet recalls]:** α- carotene3625 (2168−6168), [2937 (1708−4488)]; β- carotene 617 (296 −976), [305 (122−718)]; β-cryptoxanthin, 194 (85−327), [164 (76 −294)] lutein + zeaxanthin 3034 (1607 −4843), [2411 (1201−3694)]; lycopene 4343 (2986−7654), [4890 (2868 −10446)]. **AA FFQ, [diet recalls]:** α- carotene 2865 (1267−5490), [2151 (988−4072); β-carotene 242 (96−714), [175 (70 −419)], β-cryptoxanthin 125 (68−379), [140 (39−297)]; lutein + zeaxanthin 1936 (1057−3982), [1631 (934−2907)], lycopene 3970 (2258−7916), [3241 (1219−6129)]	**(μmol/L) Median (25th−75th percentile). White:** α- carotene 0.190 (0.131−0.302), β- carotene 0.051 (0.028−0.085), β-cryptoxanthin 0.091 (0.062−0.119), lutein + zeaxanthin 0.128 (1057−3982), lycopene 0.392 (0.295−0.476). **AA:** α- carotene 0.133 (0.094−0.233), β- carotene 0.031 (0.019−0.046), β-cryptoxanthin 0.094 (0.058−0.135), lutein + zeaxanthin 0.114 (0.089−0.141), lycopene 0.402 (0.311−0.549)	*All Pearson correlations adjusted for age, sex, education and BMI* **Antioxidant Nutrient Questionnaire & plasma carotenoids: Whites, [AA]:** α- carotene 0.33 ($P \leq 0.01$), [0.27 ($P \leq 0.05$)]; β- carotene 0.31 ($P \leq 0.01$), [0.31 ($P \leq 0.01$)]; β-cryptoxanthin, 0.28 ($P \leq 0.01$), [0.33 ($P \leq 0.01$)]; lutein + zeaxanthin 0.24 ($P \leq 0.05$), [0.32 ($P \leq 0.01$)]. **Dietary recalls & plasma carotenoids: Whites:** α-carotene 0.24 ($P \leq 0.05$), Lutein + Zeaxanthin 0.31 ($P \leq 0.01$). **AA:** α- carotene 0.24 ($P \leq 0.05$), β-cryptoxanthin 0.43 ($P \leq 0.0001$), Lutein + Zeaxanthin 0.48 ($P \leq 0.0001$), lycopene 0.28 ($P \leq 0.01$).	Small n; demographics and subject characteristics not well presented; results were not adjusted for total energy intake; Not generalizable as subjects were healthy volunteers.
Schroder et al. (2001) [40]	**(g) Mean ± SD.** β-carotene 1.9 ± 2.2 (3-day estimated food record), 7.4 ± 9.1 (FFQ),1.2 ± 1.8 (72-hr recall). The β-carotene for the FFQ was significantly different from the three day record ($P < 0.001$)	Actual plasma levels of carotenoids not reported	**Correlation coefficients.** β-carotene 0.44 (3-day food record), 0.34 (72 h recall) and 0.17 (FFQ). No significance level reported.	small n; not all participants provided blood samples; no associations with confounders conducted
Shai et al. (2005) [171]	*Adjusted for gender* **(mg) Mean ± SE. As reported:** β-carotene 827 ± 56 (24 h recalls), 1508 ± 68 (FFQ). **Energy adjusted:** 825 ± 59 (24 h recalls), 1505 ± 76 (FFQ).	**(μmol/L) Mean ± SE.** β-carotene 2.30 ± 0.097	*Log transformed and adjusted for energy and serum cholesterol.* **Without supplements:** β-carotene 0.38, $P < 0.001$ (24 h recalls) 0.35, $P < 0.001$ (FFQ's). **With supplements:** β-carotene 0.36, $P < 0.001$ (24 h recalls) 0.38, $P < 0.001$ (FFQ's).	Small n; no associations with confounders conducted
Shiriashi et al. (2013) [35]	*Mean* ± SD mg/day *B carotene − 3.08* ± 2.05	*Mean* ± SD μg/dl *B carotene − 41.0* ± 22.2	*B carotene 0.224 (P0.03)*	Assessed B carotene only
Signorello et al. (2010) [172]	*All log transformed* **(μg/day) Mean* (SD) where* is P < 0.05 for 2-sample t-test comparing mean values by race within each sex. AA female:** α- carotene 666.0* (787.5), β- carotene 5820.8* (5119.8), β-cryptoxanthin 264.1* (213.5), lutein + zeaxanthin 5025.2* (4934.4), lycopene 4892.1 (5301.7). **AA male:** α- carotene 556.2 (533.1), β- carotene 6212.2* (5750.7),	*All log transformed, except lycopene which is square root transformed* **(μg/dL) Mean* (SD) where* is P < 0.05 for 2-sample t-test comparing mean values by race within each sex. AA Female:** α- carotene 4.4* (4.8), β- carotene 21.3* (20.6), β-cryptoxanthin 10.7* (6.7), lutein + zeaxanthin 21.8* (10.4), lycopene 28.5 (12.7). **AA male:** α- carotene 2.7 (2.6),	α- carotene 0.32 ($P < 0.001$), β- carotene 0.25 ($P < 0.001$), β-cryptoxanthin 0.37 ($P < 0.001$), lutein + zeaxanthin 0.35 ($P < 0.001$), lycopene 0.18 ($P < 0.01$)	Small n; Non-fasting blood samples;

	β-cryptoxanthin 298.6* (263.4), lutein + zeaxanthin 5497.4* (5769.8), lycopene 6994.7 (5098.4). **White female:** α- carotene 419.0* (364.3), β- carotene 3203.4* (1952.5), β-cryptoxanthin 160.5* (164.0), lutein + zeaxanthin 2223.4* (1375.1), lycopene 4050.9 (2979.3). **White male:**α- carotene 572.2 (483.9), β- carotene 3617.0* (2656.1), β-cryptoxanthin 175.7* (150.6), lutein + zeaxanthin 2583.7* (2199.7), lycopene 6949.9 (5299.3)	β- carotene 13.1 (11.1), β-cryptoxanthin 8.2 (5.6), lutein + zeaxanthin 20.9* (10.0), lycopene 33.4 (17.2). **White female:** α- carotene 2.7* (2.0), β- carotene 13.8* (12.6), β-cryptoxanthin 6.4* (4.3), lutein + zeaxanthin 14.3* (6.3), lycopene 31.1 (13.6). **White male:** α- carotene 3.7 (4.8), β- carotene 11.2 (9.9), β-cryptoxanthin 6.9 (4.1), lutein + zeaxanthin 15.3* (7.0), lycopene 33.8 (14.8)		
Stryker et al. (1990) [175]	9285 ± 7210 F; 7410 ± 5806 M	**α-carotene (μg/dl)** F: 7.4 ± 6.4; M: 4.5 ± 6.1; **β-carotene (ug/dl)** F: 31.8 ± 27.7; Males: 18.5 ± 19.1; **lycopene (ug/dl)** F: 35.7 ± 16.4; M: 33.9 ± 16.1	**Plasma a-carotene & dietary carotene** Females: 1) 0.40; 2) 0.41; 3) 0.44; 4) 0.45; Males: 1) 0.29; 2) 0.34; 3) 0.32; 4) 0.36; **Plasma b-carotene & dietary carotene** Females: 1) 0.37; 2) 0.39; 3) 0.41; 4) 0.42; Males: 1) 0.27; 2) 0.33; 3) 0.31; 4) 0.36; **Plasma lycopene & dietary carotene** Females: 1) −0.03; 2) −0.04; 3) −0.01; 4) −0.02; Males: 1) 0.05; 2) 0.07; 3) 0.04; 4) 0.06; **Plasma carotenoid index** (b-carotene + 0.5 a-carotene) Females: 1) 0.38; 2) 0.40; 3) 0.42 4) 0.43; Males: 1) 0.28; 2) 0.34; 3) 0.32; 4) 0.38. *1)not calorie adjusted/ not lipid adjusted; 2) not calorie adjusted/ lipid adjusted; 3) calorie adjusted/not lipid adjusted; calorie adjusted/lipid adjusted*	Few individual dietary carotenoids reported. Significance for correlations not reported. Cross-sectional study.
Su et al. (2006) [176]	**Salad consumption Mean ± SD g/d - 18 −45 yrs:** F 39.2 ± 82.3; M 40.0 ± 90.1; **55 + yrs:** F 36.1 ± 76.6; M 37.7 ± 83.1; **Vegetable consumption Mean ± SD g/d − 18−45 yrs:** F 33.6 ± 75.2; M 36.0 ± 82.3; **55 + yrs:** F 31.3 ± 71.8; M 32.7 ± 77.6	Mean serum levels by level (L = low, M = medium, H = high) of salad/vegetable consumption (μg/dl) − **α-carotene salad**: F (L) 4.84; (M) 4.84; (H) 5.91; M (L) 3.76; (M) 4.30; (H) 4.84; **α-carotene vegetables:** F (L) 4.84; (M) 4.84; (H) 5.81; M (L) 3.76; (M) 4.30; (H) 4.84; **β-carotene salad:** F (L) 20.97; (M) 20.97; (H) 24.73; M (L) 16.13; (M) 18.28; (H) 19.35;**β-carotene vegetables:** F (L) 20.97; (M) 20.97; (H) 24.73; M (L) 16.13; (M) 18.28; (H) 19.35; **lycopene salad:** F (L) 20.43; (M) 21.51; (H) 23.12; M (L) 21.51; (M) 23.13; (H) 24.19;**lycopene vegetables:**F (L) 20.43; (M) 21.51; (H) 23.12; M (L) 21.51; (M) 23.13; (H) 24.19	There was a positive relationship between consumption (salad and vegetable) and serum carotenoids for females and males: **Salad:** α-carotene F 1.24; M 1.35; β-carotene F 1.06; M 1.27; lycopene F 1.19; M 1.15; **Vegetables**: α-carotene F 1.26; M 1.31; βcarotene F 1.21; M 1.26; lycopene F 1.18; M 1.12	
Svendsen et al. (2007) [177]	**Intake at 3 months** Control (C) and Intervention (I): **b-carotene (μg/d)** C: 3600 ± 2729; I: 7086 ± 4528; **vegetables (g/d)**C: 238 ± 144; I: 457 ± 240; **fruits** C: 322 ± 258; I: 486 ± 285; **Change in intake from baseline to 3 months** (mean, CI):**β-carotene** C: 588(−81, 1257); I: 4140(2948, 5334); **vegetables** C: 12(−33, 57); I: 245(194,	Change from baseline to 3 months: **α-carotene (uM):** C: −0.002(−0.016, 0.020); I: 0.046(0.026, 0.066); **β-carotene (uM):** C: −0.029 (−0.077, 0.019); I: 0.086(0.036, 0.150); **β-cryptoxanthin (uM)** C: 0.026(−0.004, 0.056); I: 0.055(0.021, 0.089); **Lutein (uM):** C: −0.017 (−0.039, 0.005);	**Correlations for changes in intake/plasma conc intervention group only: Change is vegetable intake and change in plasma α carotene** (r = 0.323; p = 0.0103); **change in β carotene intake and plasma β-carotene** (r = 0.234; p = 0.0135); **Correlations for intake and plasma conc. at 3 months intervention group only: fruit intake and plasma a-carotene** (r = 0.426; p = 0.0006). **cryptoxanthin** (r = 0.270; p = 0.0308); **When control subjects were added to the analysis (no increase in fruit and veg**	Those taking high does of multivitamins were not excluded or reported separately.

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Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
	296); **Fruits** C: −4(−79, 71); I: 248(176, 320)	I: 0.005 (−0.013, 0.023); **Zeaxanthin (uM):** C: −0.010(−0.020, 0.005); I: −0.002(−0.062, 0.058); **lycopene (uM):** C: 0.014(−0.004, 0.068); I: 0.073(0.009, 0.137)	**intake) there were additional significances - change from baseline to 3 months: veg intake and plasma** **α-carotene** (r = 0.422; p < 0.0001); **β-carotene** (r = 0.229; p = 0.0159); **lutein** (r = 0.255; p = 0.0073); **fruit intake and plasma a-carotene** (r = 0.221; p = 0.0198); **Intake at 3 months: vegetable intake and plasma α-carotene** (r = 0.399; p=<0.0001); **β-carotene** (r = 0.315; p = 0.0008); **cryptoxanthin** (r = 0.233; p = 0.0133); l**utein** (r = 0.270; p = 0.0041); l**ycopene** (r = 0.207; p = 0.0280);**fruit intake and plasma α-carotene** (r = 0.349; p = 0.0002). **β-carotene** (r = 0.235; p = 0.0126); **cryptoxanthin** (r = 0.319; p = 0.0008);	
Talegawkar et al. (2008) [178]	Median (IQR), (μg/day): **Average of 24 h recalls:** **α-carotene** F: 144(37 487); M: 177(41, 548); **total β-carotene** F: 3044(2029, 6525); M: 3178(1696, 5360); **dietary β -carotene** F: 2770(1409, 4933); M: 2928(1584, 6099);**cryptoxanthin** F: 98(43, 171); M: 85(30, 183); l**utein + zeaxanthin** F: 2607(1338, 5152); M: 2935(1345, 5261); **lycopene** F: 1467(502, 3827); Males: 2222(592, 5075); **Short FFQ: α-carotene** F: 349(221 517); M: 385(247, 593);**total β-carotene** F: 3048(2419, 4100); M: 2886(2304, 3682); **dietary βcarotene** F: 2561(1940, 3312); M: 2802(2147, 3529);**cryptoxanthin** F: 111(61, 197); M: 108(62, 187); l**utein + zeaxanthin** F: 2149(1676, 2832); M: 2259(1735, 3065);**lycopene** F: 2789(1622, 4248); M: 3537(2016, 5513); **Long FFQ α-carotene** F: 251(143, 431); M: 328(180, 509); **total β-carotene** F: 2707(1746, 4057); M: 2685(1776, 4574); **dietary β-carotene** F: 2211(1528, 2992); M: 2205(1534, 3424); **b-cryptoxanthin** F: 126(57, 199); M: 113(57, 193); l**utein + zeaxanthin** F: 1927(1428, 616); M: 1849(1311, 2594);**lycopene** F: 2600(1434, 4181); M: 3161(1923, 5537)	Mean ± SE (μmol/l): **αcarotene** F: 0.07 ± 0.004; M: 0.07 ± 0.005; **β-carotene non-suppl users** F: 0.64 ± 0.05; M: 0.51 ± 0.06; **β-carotene suppl users** F: 0.82 ± 0.07; M: 0.84 ± 0.09;**cryptoxanthin** F: 0.18 ± 0.01; M: 0.17 ± 0.01; **Lutein + zeaxanthin** Females: 0.32 ± 0.01; Males: 0.32 ± 0.01; **lycopene** F: 1.24 ± 0.05; M: 1.44 ± 0.06	**Average 24 h recalls:** α **-carotene** 0.41; **total** β **-carotene** 0.35; **dietary** β **carotene** 0.32; **b-cryptoxanthin** 0.44; **lutein + zeaxanthin** 0.39; l**ycopene** 0.40; **short FFQ:** α **-carotene** 0.32; **total b-carotene** 0.22; **dietary** β **-carotene** 0.12; β **-cryptoxanthin** 0.29; **lutein + zeaxanthin** 0.13; **lycopene** 0.24; **long FFQ:** α **carotene** 0.18; **total b-carotene** 0.28; **dietary b-carotene** 0.21; **b-cryptoxanthin** 0.25; **lutein + zeaxanthin** 0.20; **lycopene** 0.14. Unclear which results are significant, possibly just short and long FFQ?	
Tangney et al. (2004) [179]	**FFQ Mean ± SD (μg/day):** **α-carotene** F: 640 ± 564; M: 629 ± 386; **total β-carotene** F: 4012 ± 2276; M: 4724 ± 3395; **dietary β-carotene** F:	**Crude concentrations:** **α carotene** F: 0.07 ± 0.05; M: 0.07 ± 0.06; **β carotene** F 0.40 ± 0.21; M 0.52 ± 0.48; **β-cryptoxanthin** F: 0.16 ± 0.11; M: 0.18 ± 0.10;	**Energy adjusted correlations FFQ: a-carotene** F: 0.47; M: 0.54; Blacks 0.81; **total b-carotene** Whites: 0.44;	Small number of subjects provided blood sample, 24 h recalls were required every 2 months (total of 6)

	3760 ± 1913; M: 5429 ± 3648; **cryptoxanthin** F: 83.3 ± 82.7; M: 60.8 ± 52.2; **lutein + zeaxanthin** F: 3194 ± 3104; M: 4434 ± 5479;**lycopene** F: 8158 ± 6997; M: 10696 ± 9863.**Mean of 24 h recalls Mean ± SD (ug/day): total β-carotene** F: 4650 ± 2585; M: 4738 ± 3318; **dietary b-carotene** F: 4452 ± 2638; M: 4662 ± 3340	**lutein + zeaxanthin** F: 0.36 ± 0.16; M: 0.35 ± 0.14; **lycopene** F: 0.35 ± 0.25; M: 0.51 ± 0.34. **Lipid adjusted** **α-carotene** F: 0.07 ± 0.05; M: 0.07 ± 0.05; **β-carotene** F: 0.40 ± 0.21; M: 0.51 ± 0.38; **cryptoxanthin** F: 0.16 ± 0.11; M: 0.18 ± 0.10; **lutein + zeaxanthin** F 0.36 ± 0.16; M: 0.35 ± 0.13; **lycopene** F: 0.33 ± 0.23; M: 0.44 ± 0.28	**b-cryptoxanthin** F: 0.44; M: 0.46; Blacks 0.50; Whites 0.46; $p < 0.05$ for all.	however some subjects did not complete this number.
Tan-Un et al. (2004) [180]	Mean ± SD (IU/day - dietary carotene asthmatic subjects: 7949 ± 5314; control subjects: 7816 ± 3290	Mean ± SD (μmol/l) plasma b-carotene asthmatics: 0.888 ± 0.575; controls: 0.955 ± 0.576	Correlation between dietary carotene and plasma carotene 0.653 (significant but no p-value reported).	No significance levels reported. No dosage recorded for supplement intake. No adjustment for caloric intake, fat intake or demographics.
Tarwadi et al. (2008) [181]	Median β-carotene (μg/day): Cases (low income-LI; high income (HI)) vs controls (low income-LI; high income (HI). **Cases** (HI) F: 1307; M: 1313; (LI) F 618; M: 690; **Controls** (HI) F 1437; M: 1577; (LI) F: 675; males: 1064.	NR	Log-transformed plasma β-carotene levels were associated with dietary intakes of beta-carotene, ascorbic acid and polyphenols (R2Z 0.611, $p < 0.01$)	Less accurate method of measuring plasma concentrations. No plasma carotenoid data reported.
Thomson et al. (2007) [182]	**Mean ± SD (μg/d^{-1}):** α-carotene 1412 ± 3076; βcarotene 5781 ± 7882; cryptoxanthin 253 ± 201; lycopene 5730 ± 4537; lutein + zeaxanthin 3536 ± 4080; total carotenoid 16,712 ± 14,960; **(IU/d) supplemental β-carotene** 1551 ± 6143	Mean ± SD (μmol/L^{-1}): α-carotene 0.2 ± 0.3; βcarotene 1.1 ± 1.7; cryptoxanthin 0.2 ± 0.2; lutein + zeaxanthin 0.4 ± 0.3; lycopene 0.7 ± 0.3; total carotenoids 2.5 ± 2.0	a-carotene 0.46; b-carotene 0.34; b-cryptoxanthin 0.39; lutein + zeaxanthin 0.30; lycopene 0.27; total carotenoids 0.30. No p-values reported.	Females cancer survivors only
Toft et al. (2008) [183]	Median(5th&95th %tiles): **FFQ: β-carotene** (mg/day) F: 2174 (818−6015); M: 1553 (604−3881); **vegetables** (g/day) F: 259 (110−549); M: 263 (102−573); **Fruits** (g/day) F: 318 (21−705); M: 133 (9−533); **Diet History β-carotene** F: 3818 (944−14 468); M: 3142 (783−15 156); **vegetables** F: 299 (106−700); M: 321 (138−807); **fruits** F: 243 (35−667); M: 190 (27−582).	NR	**Correlations between plasma and FFQ: α-carotene/fruits** (0.30 M; 0.37 F); **α-carotene/veg** (0.26; 0.23 F); **α carotene/fruit&veg** (0.44 M; 0.41 F); **βcarotene/fruits** (0.28 M; 0.24 F); **β-carotene/veg** (0.28 M; 0.22 F); **β-carotene/fruit&veg** (0.38 M; 0.29 F); **lutein/fruits** (0.36 M; 0.20 F); **lutein/veg** (0.23 F); **lutein/fruit&veg** (0.34 M; 0.25 F); **zeaxanthin/fruits** (0.20 M; 0.19 F); x**eaxanthin/veg** (0.19 F); **eaxanthin/fruit&veg** (0.22 M; 0.23 F); b-**cryptoxanthin/fruits** (0.37 M; 0.30 F): b-**cryptoxanthin/veg** (0.27 M); b-**cryptoxanthin/fruit&veg** (0.40 M; 0.29 F); lycopene - nil significant	Plasma concentrations NR, correlations with diet history not undertaken, only dietary carotenoid assessed was b-carotene and this was not included in the correlation analysis.
Torronen et al. (1996) [184]	**3 low b-carotene groups: raw carrots (Group 1), carrot juice (Group 2), β-carotene capsules (Group 3). Mean ± SD βcarotene (μg/day) during 10-day habitual intake** Group 1: 4838 ± 1893; Group 2: 4600 ± 2614; Group 3: 3909 ± 1793; **B-carotene (μg/day) during 6-week supplemental period (low intake):** Group 1366 ± 231; Group 2360 ± 185; Group 3456 ± 475.	**Mean ± SD serum b-carotene (μg/l) during 10-day habitual intake period:** Group 1: 570 ± 214; Group 2: 512 ± 213; Group 3: 524 ± 269; **serum b-carotene after 6-week supplementation period (low intake):** Group 1: 452 ± 232; Group 2: 570 ± 387; Group 3: 937 ± 456.	No correlation.	Only b-carotene measured, females only, small sample size, likely unvalidated dietary assessment tool.
Tucker et al. (1999) [185,186]	[1] **Mean (μmol/L) in 5th and 95th %ile of intake: a-carotene:** F 0.03/0.25; M 0.02/0.19; **b-carotene:** F 0.14/1.14; M 0.08/0.77; **a-cryptoxanthin:** F 0.03/0.16; M 0.02/0.16; **b-cryptoxanthin:** F	[1] **Mean ± SD in males and females under 79 yrs and 80 yrs and over:** **α-carotene:** F < 80 0.12 ± 0.08; >80 0.11 ± 0.10; M < 80 0.09 ± 0.09; >80 0.10 ± 0.05; **β-carotene:** F < 80 0.51 ± 0.33; >80 0.46 ± 0.27;	**Correlations between plasma concentrations and dietary carotenoids:** **α-carotene:** F 0.33; M; 0.18; **total β-carotene:** F0.36; M 0.25; **dietary βcarotene:** F0.30; M0.16 ($p < 0.05$);	Non-fasting samples, dietary fat not assessed.

(*continued on next page*)

Table 2 (*continued*)

Source	Dietary carotenoid intake	Plasma carotenoid concentrations	Associations between diet and plasma correlations	Limitations
	0.07/0.54; M 0.05/0.44; **lutein + zeaxanthin:** F 0.19/0.99; M0.20/0.89;**lycopene:** F 0.13/1.3; M 0.12/1.4; **total carotenes (IU):** F 9916 ± 6198; M 8319 ± 5879 [2]; **Mean ± SD (ug/day) a-carotene:** F 862 ± 781; M 656 ± 605; **total b-carotene:** F 4508 ± 2925; M 3793 ± 2608; **dietary b-carotene:** F 4216 ± 2609; M 3520 ± 2474;**b-cryptoxanthin:** F 75.1 ± 71.4; M 63.0 ± 65.1; **lycopene:** F 7002 ± 5558; M 7636 ± 5984; **lutein + zeaxanthin:** F 3087 ± 2380; M 2678 ± 1934; **Fruit and Veg intake (servings/day):** F 5.1 ± 2.4; M 4.4 ± 2.2	M < 80 0.33 ± 0.20; >80 0.40 ± 0.19; **α cryptoxanthin:** F < 80 0.09 ± 0.04; >80 0.08 ± 0.04; M < 80 0.08 ± 0.04; >80 0.03 ± 0.04; **β-cryptoxanthin**: F < 80 0.27 ± 0.17; >80 0.25 ± 0.16; M < 80 0.20 ± 0.12; >80 0.20 ± 0.10; **lutein + zeaxanthin:** F < 80 0.54 ± 0.26; >80 0.46 ± 0.22; Males <80 0.48 ± 0.24; >80 0.46 ± 0.21; **lycopene:** F < 80 0.62 ± 0.34; >80 0.46 ± 0.35; M < 80 0.65 ± 0.36; >80 0.47 ± 0.41 [2]; **Mean ± SD (μmol/L) α-carotene:** F 0.117 ± 0.087; M 0.082 ± 0.053; **β-carotene:** F 0.51 ± 0.34; M 0.33 ± 0.23; **β-cryptoxanthin:** F 0.27 ± 0.17; M 0.20 ± 0.12; **lutein + zeaxanthin:** F 0.56 ± 0.27; M 0.52 ± 0.23 **lycopene:** F 0.61 ± 0.36; M 0.64 ± 0.38;	**β-cryptoxanthin:** F 0.44; M 0.32; **lutein + zeaxanthin**: F 0.27; M 0.10 (NS). **lycopene:** F 0.35; M 0.21; All p values <0.0001. **Correlations between plasma concentrations and F&V intake: α-carotene:** F 0.25; M 0.17; **βcarotene:** F 0.27; M 0.17; **β-cryptoxanthin:** F 0.33; M (NS); **lutein + zeaxanthin**: F 0.17; M (NS). **lycopene:** F 0.14; M (NS); p < 0.01 for all female correlations with F&V intake and <0.05 for the two significant correlations for males.	
VandenLangenberg et al. (1996) [50]	Mean ± SD (μg/day) carotenoid intakes from HHHQ and USDA-NCI: **HHHQ:** A carotene: 283 ± 240; β-carotene: 1553 ± 1005; cryptoxanthin: 80 ± 53; lutein + zeaxanthin: 816 ± 622; lycopene: 715 ± 563; total carotenoids: 3446 ± 1890; **USDA-NCI:** α-carotene: 267 ± 186; β-carotene: 1490 ± 849; β-cryptoxanthin: 29 ± 28; lutein + zeaxanthin: 962 ± 642; lycopene: 1889 ± 1239; total carotenoids: 4639 ± 2386	Mean ± SD (nmol/L): α-carotene 87 ± 61; β-carotene 334 ± 227; cryptoxanthin 182 ± 129; lutein + zeaxanthin 287 ± 126; lycopene 496 ± 245	Correlations between carotenoid concentrations in serum and diet: **HHHQ:** α-carotene 0.33; β-carotene 0.27; b-cryptoxanthin 0.48; lutein + zeaxanthin 0.28; lycopene 0.29; **USDA-NCI:** α-carotene 0.32; β-carotene 0.32; b-cryptoxanthin 0.53; lutein + zeaxanthin 0.24; lycopene 0.25. All correlations significantly different from 0 (p < 0.05). No difference between HHHQ and USDA-NCI.	FFQ assessed intake over preceding 12 months, serum carotenoids may reflect intake over a shorter time period.
Vioque et al. (2007) [187]	Mean ± SD (μg/day) of intake in males and females. **αcarotene:** F 832.2 ± 504.2; M 720.3 ± 558.7; **β-carotene:** F 4358.2 ± 2134.3; M 4000·1 ± 2076·4; **cryptoxanthin:** F 313·6 ± 231·8; M 276·1 ± 184·9; **lutein + zeaxanthin** F 4600·1 ± 3063·3; M 4283·0 ± 2387·3 **lycopene:** F 4042·8 ± 2634·7; M 4009·4 ± 2396·3;	Mean ± SD (μmol/L) plasma concentrations in males and females. **α-carotene:** F 0.096 ± 0.14; M0.061 ± 0.07; **β-carotene:** F 0.304 ± 0.34; M 0.196 ± 0.23; **-cryptoxanthin;** F 0.135 ± 0.15; M 0.107 ± 0.13; **lutein + zeaxanthin** F 0.153 ± 0.16; M 0.139 ± 0.13**lycopene;** F 0.703 ± 0.86; M 0.474 ± 0.56	Correlations between dietary intake and plasma concentrations (dietary intake adjusted for energy intake and plasma concentrations adjusted for cholesterol). **α-carotene:** Total 0.21; Females 0.17; Males 0.21; **β-carotene:** Total 0.19; Females 0.20; Males 0.14; **cryptoxanthin:** Total 0.20; Females 0.16; Males 0.23; **lycopene:** Total 0.18; Females 0.14; Males 0.21; **utein + zeaxanthin**: Total 0.19; Females 0.13; Males 0.07. All "total" correlations significant (no p-values reported). No other significances reported.	Non-fasting samples, significance of correlations unclear.
Vioque et al. (2013) [36]	mean ± SD μg/day **α carotene** 536 ± 468 **β carotene** 4499 ± 2438 **lutein/zeaxanthin** 3157 ± 2455 **lycopene** 4410 ± 2727 ±360 ± 253	mean ± SD μmol/L α carotene 0.15 ± 0.14 β carotene 0.40 ± 0.30 Lutein/zeaxanthin 0.32 ± 0.13 Lycopene 0.72 ± 0.62 Cryptoxanthin0.22 ± 0.15	α carotene 0.31 (P < 0.01) β carotene 0.21 (P < 0.01) Lutein/zeaxanthin 0.26 (P < 0.01) Lycopene 0.05 Cryptoxanthin0.26 (P < 0.01)	Women only
Wahlqvist et al. (1994) [188]	Mean ± SD (mg/day) in females and males at baseline/12 months: Supplement group: **α-carotene:** F 1.5 ± 1.2/1.5 ± 1.1; M 1.2 ± 1.2/1.5 ± 1.5; **β-carotene:** F 3.5 ± 2.1/3.7 ± 2.2; M 2.9 ± 2.1/3.2 ± 2.4; **cryptoxanthin:** F 0.3 ± 0.6/0.2 ± 0.3; M 0.2 ± 0.3/ 0.2 ± 0.6;	Mean ± SD (nmol/L) in females and males at baseline/12 months: Supplement group: **α-carotene:** F 47 ± 40/102 ± 85; M36 ± 39/85 ± 72;**β-carotene:** F 446 ± 1027/2367 ± 2448; M 280 ± 447/ 2139 ± 2666; **b-cryptoxanthin:** F 281 ± 328/297 ± 242; M 193 ± 183/247 ± 239; **lutein + zeaxanthin:**	Correlations between serum concentrations and dietary intake in females and males: **Females:** b-cryptoxanthin 0.41(p < 0.0001); **Males:** α-carotene 0.27(p < 0.01); β-carotene 0.25(p < 0.01);	

	lutein + **zeaxanthin:** F 2.0 ± 1.5/ 2.3 ± 1.8; M 1.8 ± 1.2/1.9 ± 1.2; **lycopene:** F 2.6 ± 3.1/2.7 ± 2.4; M 2.0 ± 1.8/ 1.8 ± 1.7; Placebo group: **α-carotene:** F 1.5 ± 1.4/ 1.9 ± 1.3; M 1.1 ± 1.2/0.6 ± 0.4; **βcarotene:** F 3.6 ± 3.4/4.8 ± 3.1; M 4.7 ± 5.0/4.1 ± 2.8; **-cryptoxanthin:** F 0.3 ± 0.4/0.3 ± 0.5; M 0.3 ± 0.3/ 0.2 ± 0.3; **lutein** + **zeaxanthin:** F 2.1 ± 2.2/ 3.0 ± 4.7; M; 2.7 ± 2.6/2.7 ± 2.0**lycopene:** F 1.7 ± 1.2/1.9 ± 1.2; M 2.5 ± 4.6/ 1.9 ± 1.9;	F 569 ± 681/660 ± 712; M 521 ± 619/509 ± 476; **lycopene:** F 285 ± 666/440 ± 619; M 255 ± 296/530 ± 521; Placebo group: **α-carotene:** F 37 ± 32/37 ± 32; M 45 ± 41/55 ± 46;**β-carotene:** F 236 ± 247/235 ± 219; M258 ± 275/270 ± 357; **b-cryptoxanthin:** F 366 ± 654/291 ± 292; M 213 ± 273/249 ± 299; **lutein** + **zeaxanthin:** F 512 ± 456/589 ± 523; M 547 ± 454/604 ± 494 **lycopene:** F 179 ± 187/224 ± 201; M 271 ± 286/327 ± 341;	b-cryptoxanthin 0.31($p < 0.001$); lutein + zeaxanthin 0.26($p < 0.01$).	
Wallstrom et al. (2001) [189]	Mean ± SD (mg/day) **Food derivedβ-carotene:** F 3.86 ± 3.41; M 2.87 ± 2.81; **Total βcarotene (incl. suppl):** F 3.95 ± 3.50; M 2.88 ± 2.82	Mean ± SD (mmol/L) serum b-carotene: F 0.61 ± 0.49; M 0.39 ± 0.32	Correlations between serum b-carotene and total dietary b-carotene: Females 0.31($p > 0.001$); Males 0.25 ($p < 0.001$).	Dietary fat not measured, few carotenoids assessed, non-fasting samples.
Wawrzyniak et al. (2013) [37]	Mean ± SD (mg/day) **α carotene** 1.03 ± 0.79 **β carotene** 3.47 ± 1.84 **lutein/zeaxanthin** 2.64 ± 1.29 **cryptoxanthin** 0.46 ± 0.41 **Lycopene** 2.15 ± 1.25	Mean ± SD (nmol/L) **α carotene** 79.5 ± 60.2 **β carotene** 459.4 ± 421.1 **lutein/zeaxanthin** 293.4 ± 108 **cryptoxanthin** 504.8 ± 283.6 **Lycopene** 611.2 ± 292	**α carotene** 0.25 **β carotene** 0.37 **lutein/zeaxanthin** 0.29 **cryptoxanthin** 0.30 **Lycopene** 0.24	Women only
Willet et al. (1983) [190]	Carotene 5650 IU ± 4020	Total carotenoids 179 ± 53 μg/dL	Total carotenoids crude value r = 0.29, P 0.02. Plasma Carotenoids inversely associated with quetlets index (r = −0.26, P < 0.05)	Not clear how total carotene was calculated
Wolters et al. (2006) [191]	β - carotene (mg) 6.71 ± 4.37	β - carotene (μmol/L) 1.12 ± 0.88	β carotene r = 0.173 P 0.025)	Females only
Ylonen et al. (2003) [192]	α carotene M 0.05 F 0.13 β - carotene (mg) M 1.74 F 2.13 lycopene M 0.82 F 0.61	α carotene M 0.12 ± 0.11 F 0.20 ± 0.16 β - carotene (μmol/L) M0.51 ± 0.30 F 0.73 ± 0.42 Lycopene M0.31 ± 0.24 F 0.30 ± 0.18	**α carotene** M r = 0.31 P 0.005 F r = 0.45 P < 0.001 **β carotene** Males NS F r = 0.33 P 0.008 **lycopene** M r = 0.41 P 0.002, F r = 0.33 P 0.008	
Yong et al. (1994) [51]	**Diet records (ug/day)** α carotene 573 ± 590, β carotene 2652 ± 2336,β cryptoxanthin30 ± 40 Lutein 1860 ± 1543 Lycopene 3056 ± 2608 total 8171 ± 4998 **FFQ** α carotene 746 ± 685 β carotene3335 ± 2154 β cryptoxanthin38 ± 41 Lutein 2390 ± 1786 lycopene 3353 ± 1991 total 9862 ± 5177	α carotene (mmol/L) 0.11 ± 0.08 β carotene 0.34 ± 0.19, β cryptoxanthin 0.17 ± 0.05 lutein 0.46 ± 0.15 lycopene 0.58 ± 0.24 total 1.66 ± 0.54	**Diet records** αcarotene 0.59 β carotene0.52 βcryptoxanthin 0.49 lutein, 0.29 lycopene 0.41 total 0.51 **FFQ** α carotene 0.52 β carotene 0.44 β cryptoxanthin 0.30 Lutein 0.29 lycopene0.28 total 0.43	

NR — not reported, DR — diet record, FR — food record, WR — weighed record, FFQ — food frequency questionnaire, DHQ — diet history questionnaire, UC — unclear, F&V — fruit and vegetable, DQI — diet quality index, F — females, M — males.

United States Department of Agriculture (USDA) database [42] (n = 35), followed by the National Cancer Institute (NCI) (n = 10) and the University of Minnesota (n = 10) food and nutrient databases.

The mean reported dietary intakes of carotenoids, by diet assessment method are reported in Table 3. The dietary carotenoid intakes (weighted mean from meta-analysis), in descending order, were: lycopene (4555.4 μg/day), β-carotene (3679.8 μg/day) lutein/zeaxanthin (2363.6 μg/day), α-carotene (814.4 μg/day) and cryptoxanthin (186.3 μg/day). When sub-analysis was completed by sex, females had higher reported intakes than males for α- and β-carotene but not for cryptoxanthin, lutein/zeaxanthin or lycopene.

3.2. Biochemistry

Blood samples were collected from participants in a fasting state in 88 studies, with 26 in a non-fasted state. In studies where participants were fasted, 49 did not specify the length of fasting time, 13 studies reported that it was overnight, 14 reported a 10–12 h fast, nine studies reported four to 8 h, and two studies reported that only a portion of the study sample fasted. High performance liquid chromatography (HPLC), which is considered the gold standard analytical technique for analysis of carotenoids, was used to assess plasma carotenoids in all studies, except nine which used alternative methods such as spectrophotometry (Table 1), while in 11 studies the method was unclear.

The most commonly assessed plasma carotenoid was β-carotene, assessed in 80% of studies (n = 123), followed by α-carotene (61%, n = 87) and lycopene (59%, n = 84). It was more common to assess lutein and zeaxanthin as a combined variable (n = 48 studies) than either of these carotenoids individually (n = 37 and n = 20, respectively).

A total of 48 studies reported a combined variable of 'total carotenoids', however very few provided details as to how the 'total' was calculated. The most common report (n = 10) was the sum of α-carotene, β-carotene, cryptoxanthin, lycopene and lutein/zeaxanthin [19,31,43–51].

Results from the meta-analysis indicate that the weighted mean plasma carotenoid concentrations were, in descending order: lycopene 0.62 μmol/L (95%CI: 0.61, 0.63, n = 56 studies), β-carotene 0.47 (0.46, 0.48, n = 78), lutein/zeaxanthin 0.31 (0.30, 0.32, n = 31), cryptoxanthin 0.17 (0.17, 0.18, n = 44) and α-carotene 0.12 (0.11, 0.13, n = 53). In the sub-analysis by sex, females had higher (not statistically significant) plasma concentrations of the carotenoids α carotene, β carotene, cryptoxanthin, lutein/zeaxanthin compared with males ranging from 1 to 7% higher but not lycopene where males had values approximately 16% higher.

3.3. Correlations

Weighted mean correlations between diet and plasma carotenoids by dietary assessment method are reported in Table 4. The strongest correlation between diet and plasma values was for cryptoxanthin, with a mean correlation coefficient of (r = 0.38; 95% CI 0.34 to 0.42) Fig. 2. This was followed by α-carotene (r = 0.34; 95% CI 0.31, 0.37) Fig. 3, lycopene (r = 0.29; 95% CI 0.26, 0.32), lutein/zeaxanthin (r = 0.29; 95% CI 0.26, 0.33) and β-carotene (r = 0.27; 95% CI 0.25, 0.29). Females had stronger correlations than males for all carotenoids except, lycopene. It was found that fasting was not a confounding factor for the observed association between serum carotenoids levels and dietary intakes. Although not used in many studies, food records tended to demonstrate the strongest

Table 3
Mean reported dietary intakes of each carotenoid by dietary assessment type: results from meta analysis.

	Mean intakes (ug/day)	95% Confidence interval
α carotene		
All (n = 48)	814.4	584.5, 1044.3
24 h recall (n = 5)	277.9	157.5, 398.4
Diet history (n = 2)	84.5	47.3, 121.6
FFQ (n = 41)	869.3	626.3, 1112.3
Food record (n = 10)	892.3	726.6, 1057.9
β carotene		
All (n = 82)	3679.8	3265.8, 4093.8
24 h recall (n = 18)	2341.4	2075.5, 2607.3
Diet history (n = 8)	3296.9	2521.7, 4072.0
FFQ (n = 67)	3924.7	3383.8, 4465.5
Food record (n = 16)	3201.7	2223.0, 4180.3
Cryptoxanthin		
All (n = 37)	186.3	172.0, 200.6
24 h recall (n = 2)	178.8	171.1, 340.5
Diet history (n = 0)	X	X
FFQ (n = 37)	189.9	175.4, 204.5
Food record (n = 7)	106.4	68.1, 144.7
Lutein/Zeaxanthin		
All (n = 38)	2363.6	2221.0, 2506.3
24 h recall (n = 2)	3293.9	2947.9, 3639.8
Diet history (n = 0)	X	X
FFQ (n = 11)	2423.1	2293.6, 2552.6
Food record (n = 6)	1018.4	869.9, 1166.9
Lycopene		
All (n = 51)	4555.4	3586.1, 5324.7
24 h recall (n = 5)	1476.3	1072.5, 1880.2
Diet history (n = 2)	723.5	464.7, 982.3
FFQ (n = 43)	4965.5	3966.6, 5964.3
Food record (n = 11)	3116.2	2672.0, 3560.4

X Meta analysis not possible as not enough/no studies in this category.

Table 4
Mean correlation values derived by meta-analysis of similar studies for each carotenoid, and by dietary assessment method.

	Mean correlation	95% Confidence interval
α carotene		
All studies (n = 41)	0.34	0.31, 0.37
24 h recall (n = 10)	0.32	0.28, 0.35
Diet history	X	X
FFQ (n = 29)	0.34	0.30, 0.38
Food record (n = 7)	0.45	0.32, 0.56
Questionnaire (n = 5)	0.26	0.10, 0.40
β carotene		
All studies (n = 73)	0.27	0.25, 0.29
24 h recall (n = 12)	0.29	0.25, 0.34
Diet history (n = 3)	0.33	0.12, 0.51
FFQ (n = 53)	0.27	0.24, 0.29
Food record (n = 14)	0.27	0.24, 0.31
Questionnaire (n = 4)	0.29	0.10, 0.46
Cryptoxanthin		
All studies (n = 35)	0.38	0.34, 0.42
24 h recall (n = 6)	0.41	0.32, 0.49
Diet history (n = 0)	X	X
FFQ (n = 25)	0.39	0.35, 0.43
Food record (n = 5)	0.47	0.310 0.61
Questionnaire (n = 3)	0.25	0.17,0.33
Lutein/Zeaxanthin		
All studies (n = 28)	0.29	0.26, 0.33
24 h recall (n = 4)	0.39	0.34, 0.45
Diet History (n = 0)	X	X
FFQ (n = 23)	0.26	0.22, 0.29
Food record (n = 1)	0.44	0.28, 0.58
Questionnaire (n = 4)	0.39	0.23, 0.54
Lycopene		
All studies (n = 42)	0.29	0.26,0.32
24 h recall (n = 6)	0.3	0.20, 0.42
Diet history (n = 0)	X	X
FFQ (n = 27)	0.26	0.22,0.29
Food record (n = 7)	0.41	0.35, 0.46
Questionnaire (n = 3)	X	X

X = metanalysis not possible as not enough studies.

correlations between diet and plasma values, while general 'questionnaires' demonstrated the weakest.

4. Discussion

The present review identified 142 studies that had reported on the validation of a dietary intake assessment method against plasma carotenoid concentrations as biomarkers of fruit and vegetable intakes in adults. In general, the quality of studies included in this review was high with approximately 80% achieving a positive rating. The majority of studies were of cross-sectional design with healthy adults of Caucasian background, with few evaluations conducted in other ethnicities, such as African American, Hispanics and Asian populations. A lack of diversity across study populations means that current validated dietary assessment tools do not necessarily apply across nationally representative populations and future studies should include a wider ethnicity base.

FFQs were the most common type of dietary assessment method used in the included studies. This is not surprising given that this method typically assesses dietary intake over longer reporting periods compared with weighed records or 24 h recalls. The reporting periods of the FFQs varied between the previous one month and 12 months. However, despite the FFQs ability to capture food intake over a longer time period, this review indicates that the strength of relationships were typically less strong. This is to be expected, and partly explained by the considerable range in the number of food items included in the food lists used in FFQs in particular the number of fruit and vegetable items, and the half-life of plasma carotenoids of 26–76 days [17]. Approximately one third of studies that used an FFQ included details on the reporting period, while just over one half provided information regarding the food items included. The limited detail for some FFQs and the heterogeneity in the food lists, specifically fruit and vegetable items, used to measure dietary intake of carotenoids makes interpretation difficult.

Overall the correlations found in this review were weak to moderate ranging from 0.26 to 0.47, however these results need to be considered in context with the amount of confounding variables of using carotenoids as a biomarker including adiposity, infection, differences in absorption, digestion. Fruits and vegetables are quite varied in their composition of carotenoids which makes selection of a single carotenoid as a biomarker an arduous task. β carotene and lycopene were reported as the most abundant carotenoids

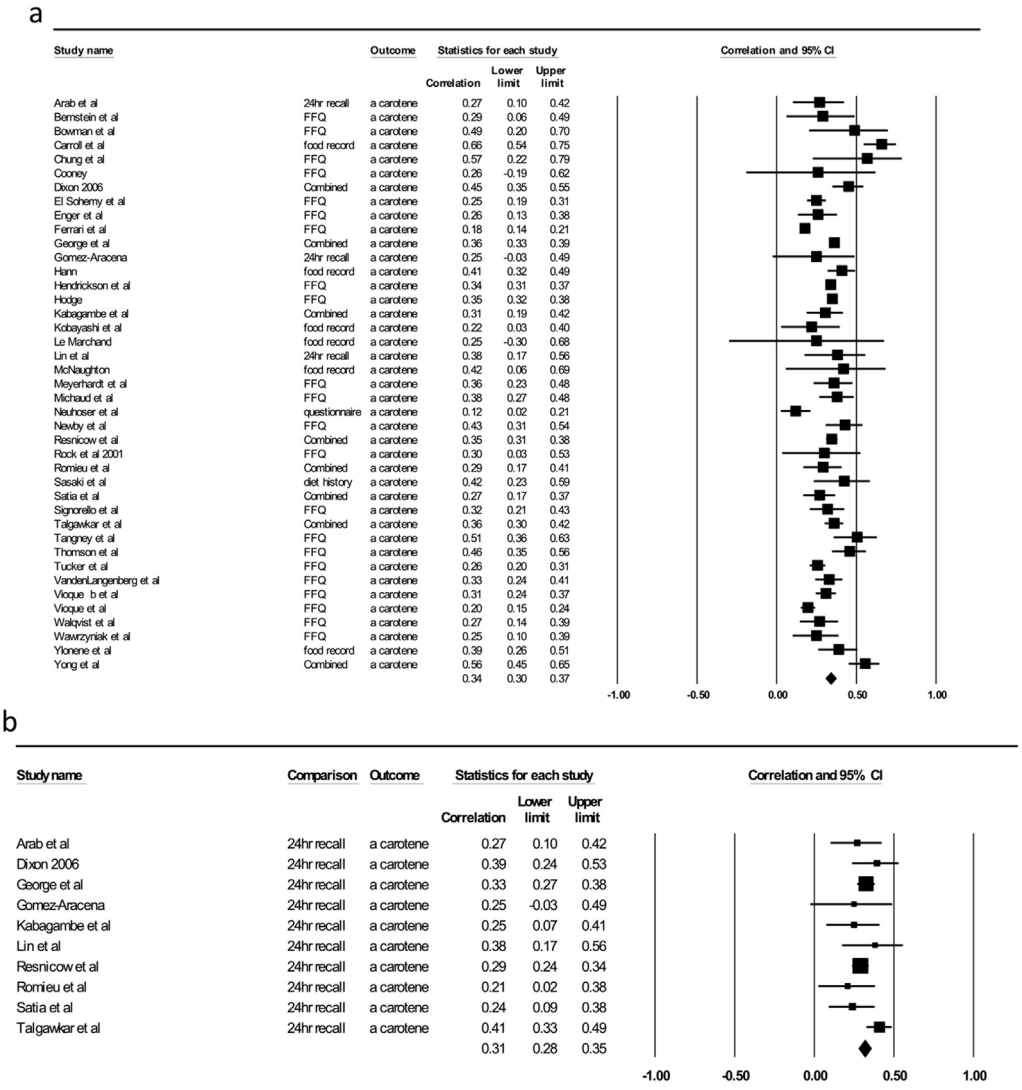

Fig. 2. a: Forest Plot correlation α carotene and all dietary methods from random effects model. b: Forest Plot correlation a carotene and 24 h recall. c: Forest Plot correlation a carotene and food frequency questionnaire (FFQ). d: Forest Plot correlation a carotene and food records. e: Forest Plot correlation a carotene and dietary questionnaires.

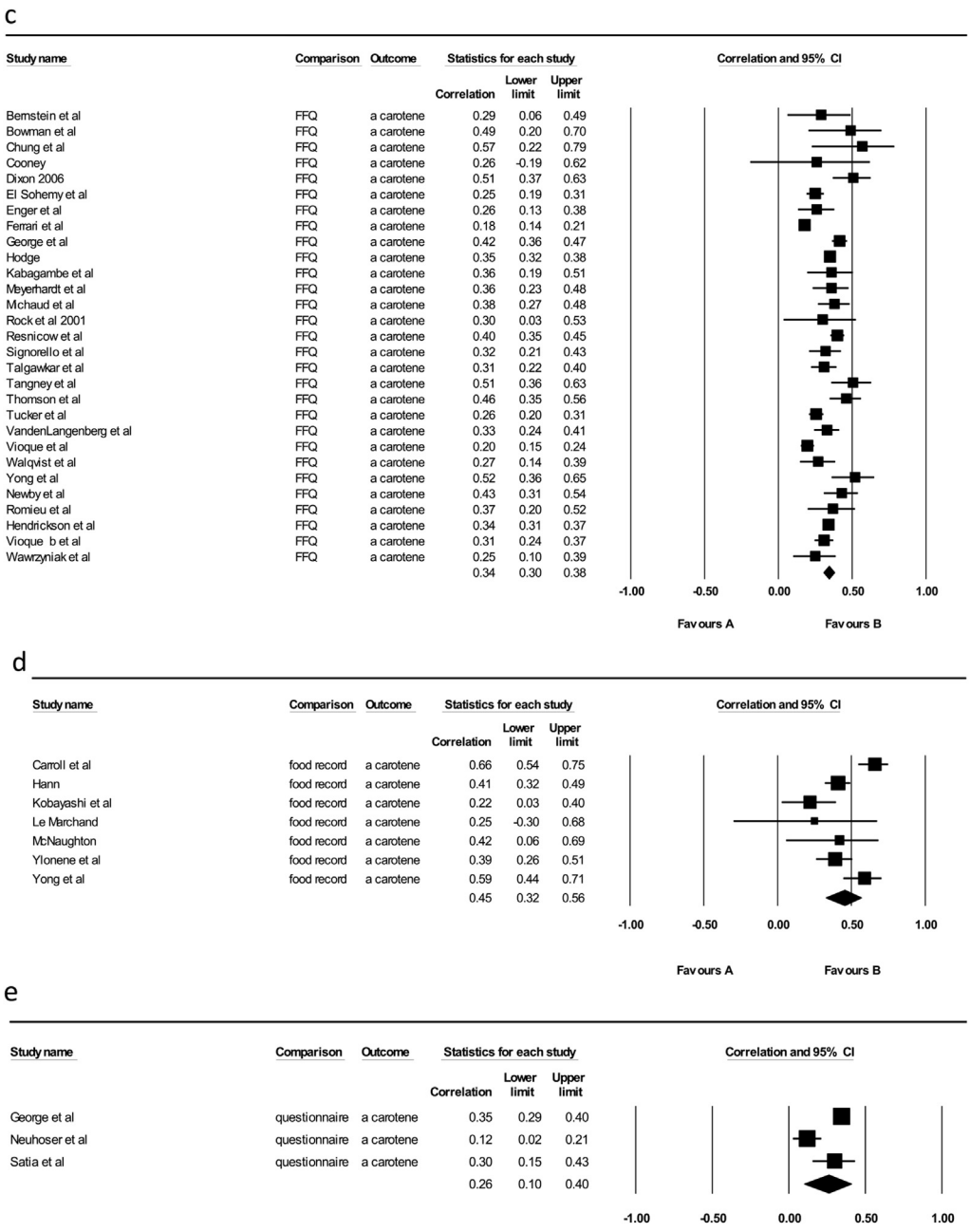

Fig. 2. (*continued*).

consumed while β and α carotene were the most commonly assessed biochemically. The strongest associations between diet and plasma carotenoids were cryptoxanthin and α-carotene. From this review, we conclude that in order to achieve the best estimate of carotenoid intake, food records should be used.

Food records showed the strongest correlation with plasma concentrations and this may be due to extra detail provided in this dietary assessment method such as weight or measure of the actual food item, brand of food and cooking method, which allows for more accurate alignment of the consumed item with matching foods in nutrient databases and hence carotenoid intake estimation. However it is noted that food records carry a high researcher and participant burden, and are expensive to collect and analyse. Higher correlations may also be attributed to the shorter time frame with food records typically kept for a period of three to seven days and including both weekdays and weekends and hence more proximal to plasma concentrations. It should also be noted that FFQs and estimated food records both have limitations in terms of accurate assessment of carotenoid intakes, compared to alternate measures of dietary assessment such as weighed food records. Studies using brief or generic questionnaires ($n = 11$) produced the poorest associations. This is not surprising given these non-standard approaches may not validly represent usual dietary intake, but rather provide a general overview of specific aspects of dietary intake only such as serves of fruit and vegetables.

Many of the studies were cross-sectional in design, meaning dietary intake and biomarkers were assessed at a single time point. Whilst this was suited to the specific aim of studies examining associations between intake and biomarkers, depending on the dietary intake method it is likely that the biomarker measurement

and assessment of dietary intake did not cover the exact same time period, hence reducing the potential to detect relationships as statistically significant. The issue as to whether a single biomarker assessment reflects a person's usual or longer-term intake, or simply recent intake has been raised previously [52]. However, it is usually assessment of longer-term intake that is more appropriate for evaluating chronic diseases risk rather than short-term intake. Further work is needed to determine whether measurement of carotenoids in other samples types, e.g. erythrocytes, adipose tissue provide a more suitable, long-term biomarker of carotenoid intake.' 'It has been suggested that the less invasive measure of skin carotenoid concentrations are potentially better measures of longer term marker of intake however skin has higher turnover [54,55] but limited studies have been conducted to date.

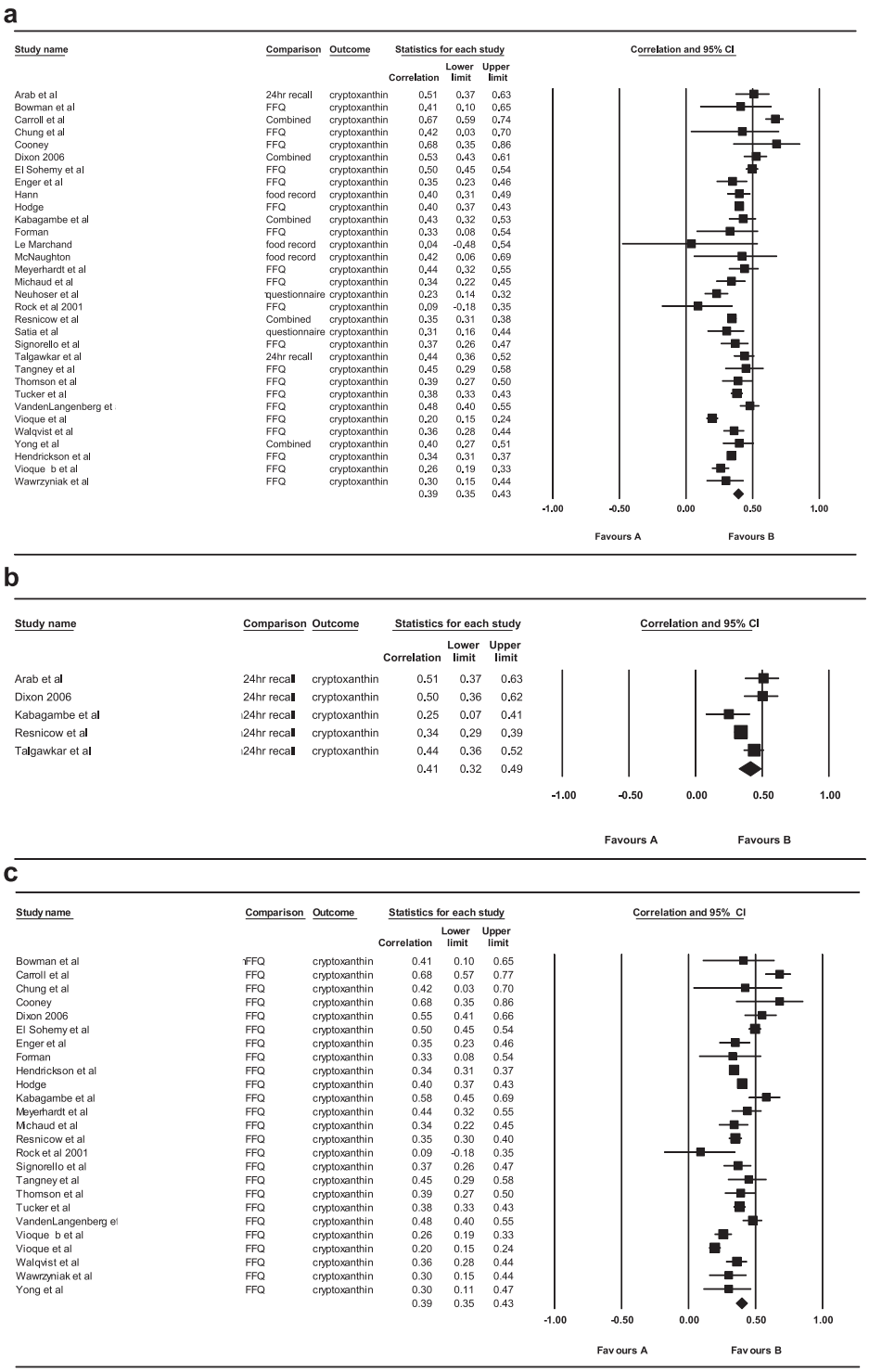

Fig. 3. a: Forest Plot correlation Cryptoxanthin and all dietary methods from the random effects model. b: Forest Plot correlation Cryptoxanthin and 24 h recall. c: Forest Plot correlation Cryptoxanthin and Food Frequency Questionnaire. d: Forest Plot correlation Cryptoxanthin and Food Records. e: Forest Plot correlation Cryptoxanthin and Dietary Questionnaire.

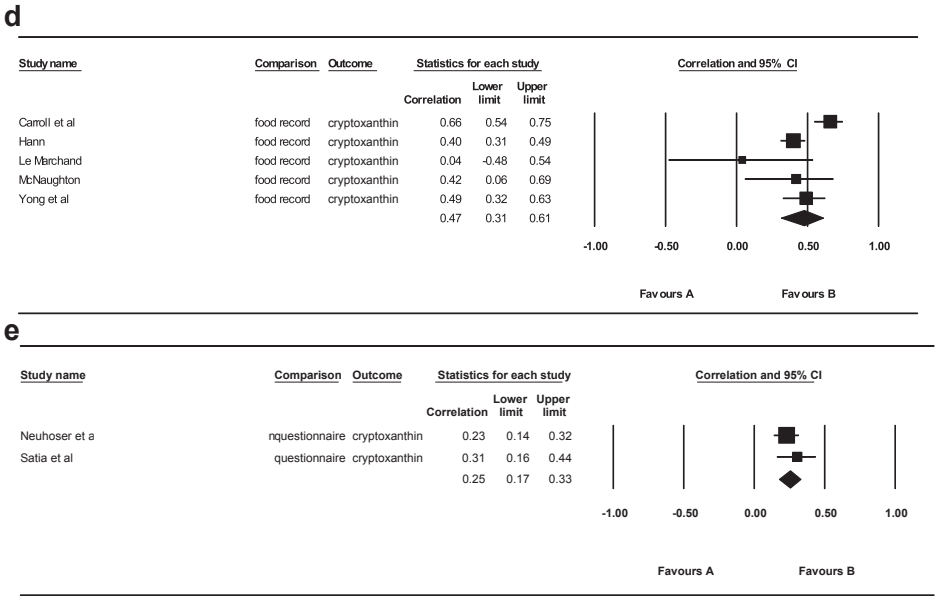

Fig. 3. (*continued*).

Although dietary assessment methods have a number of limitations, including over- or under-reporting, biomarkers are an objective marker of dietary intake that can be used to examine relationships with disease risk [56,57]. It is acknowledged that using carotenoids as biomarkers also has some limitations. For example, plasma carotenoid concentrations can be influenced by a number of factors including: an individual's baseline plasma carotenoid concentrations; the intra and inter variability in individuals digestion and absorption; the amount of fat in the diet; cooking methods used when preparing carotenoid rich foods; and vitamin A status. α and β -carotene and cryptoxanthin are readily converted to vitamin A in the body, such that an individual with low vitamin A status will likely have higher conversion rates and this may reflect in having lower carotenoid concentrations. The use of carotenoids also carry some controversies such that male smokers supplemented with β-carotene were found to have higher incidence of lung cancer than compared with those who received no supplement. While plasma concentrations of carotenoids have their limitations, they are still a good measure of dietary intake, particularly when you compare to the limitations of reported dietary intakes. Given that assessing nutritional biomarkers is not feasible in many studies, particularly large scale epidemiological studies, it is important that the dietary assessment methods used have at least been validated against biomarkers in a representative sample of the population in which they are to be administered. This could lead to increased confidence in the findings from studies using these validated methods.

The USDA database was the most common nutrient database used across the included studies, followed by NCI and University of Minnesota. This is not surprising given the majority of studies (68%) were undertaken within the USA. However, the popularity of these databases in included studies conducted outside the USA is likely due to the regular updates (all revised in 2013) and extensive range of nutrients available (range 140–180 nutrients). All three databases report on individual food carotenoid levels except for the estimates of lutein and zeaxanthin which are combined, due to difficulty in resolving the HPLC peaks for lutein and zeaxanthin, as a result of their similar retention time. Limitations of these databases for studies conducted outside the USA are that the estimates are based on the US food supply and therefore will not reflect true carotenoid compositions of foods sources from other countries. This will explain some variation in the correlation values in included studies using these databases, but are not from the USA. An additional consideration could also include how many items or questions are included in the dietary assessment method, when using questionnaires, compared to the carotenoid database. For example if an FFQ contained 100 items but only a few of these foods captured major sources of dietary carotenoids in this population, this would limit the assessment by underestimating intake.

β-carotene and lycopene were the dietary carotenoids assessed most frequently in the included studies, and not surprisingly also the two carotenoids for which plasma concentrations were highest and hence evidence exists examining the relationship between intake and disease risk [58]. However the strongest correlations were found for cryptoxanthin and α-carotene, and not β-carotene and lycopene. This is likely to be due to the increased variety of food items containing β-carotene and lycopene in FFQs and there are less food sources of cryptoxanthin.

The strongest correlations between dietary intake and plasma levels were found for cryptoxanthin and a-carotene. This is likely due to the fact that these carotenoids are rarely included in dietary supplements, which eliminates the potential confounding effect of supplemental doses. The moderate correlations found may be attributed to these carotenoids being highly prevalent in fruits and not vegetables. It is well documented that individuals are more likely to meet fruit targets than vegetable targets [59].

There was large variability in reporting of the fasting time of when blood specimens were collected. This makes direct comparisons difficult especially when in some studies, only a proportion of participants were fasted. As carotenoids enter the blood stream within 3–4 h after food consumption, which is also dependent on the amount of fat in a meal, whether the food is cooked/uncooked and the type of food (or supplement), for example the relative bioavailability of β-carotene from vegetables compared with purified β-carotene ranges between 3 and 6% for green leafy vegetables, 19 and 34% for carrots and 22 and 24% for broccoli [60], the fasting time could affect the overall comparisons with diet and likely to have contributed to the variability in findings across the included studies.

4.1. Limitations

This review was limited to studies published in the English language and may be predisposed to a publication bias and an

overrepresentation of studies that found positive associations between diet and plasma biomarkers. There was a high level of statistical heterogeneity among the included studies which indicates that the results should be interpreted with caution. We addressed statistical heterogeneity by reporting random effects meta-analysis and sub-group analyses. The potential sources of heterogeneity include variations in dietary assessment methods, the participant populations including sex, age and ethnicity, the range of plasma carotenoids assessed and the differing study protocols. The review was also limited by the less than optimal methodological quality of some of the included studies. However strengths include the large number of studies evaluated, the registered review methodology that adheres to the PRISMA guidelines for reporting of systematic reviews and the provision of meta-analyzed reference ranges for both plasma carotenoid concentrations and dietary intakes and the relationship between the two variables.

In conclusion this review summarizes typical intakes and plasma concentrations and their expected associations between the two. These will assist researchers conducting future validation studies in assessing the performance of their dietary intake instrument. It will also provide confidence in the use of dietary assessment tools as meaningful measures of fruit and vegetable intake.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jnim.2015.05.001.

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